TURNING CHARACTERISTICS OF THE BELL 100 TON SURFACE EFFECT SHIP

Kenneth Randall Myers

LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIF. 93940

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

TURNING CHARACTERISTICS OF THE BELL 100 TON SURFACE EFFECT SHIP

by

Kenneth Randall Myers

Thesis Advisor: G.J. Thaler

June 1973

T155[illegible]

Approved for public release; distribution unlimited.

Turning Characteristics of the Bell 100 Ton Surface Effect Ship

by

Kenneth Randall Myers
Lieutenant, United States Navy
B.S., United States Naval Academy, 1965

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 1973

LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA. . . 93940

ABSTRACT

The turning characteristics of the Bell 100 ton captured Air Bubble Surface Effect Ship (CAB/SES) are studied with the aid of the Oceanic Incorporated computer simulation. The craft's motions for straight runs, straight runs with waves and turning runs under calm water conditions, are compared with the final set of computer simulation turning maneuvers with waves involving changing speeds, wavelengths, wave amplitudes, and final rudder angles.

TABLE OF CONTENTS

I. INTRODUCTION ---------- 10

A. CAB/SES DEVELOPMENT ---------- 10

B. BELL 100B CAB/SES PROGRAM ---------- 13

1. Simulation Statistics ---------- 13

2. Description of Program ---------- 14

3. Formulation of State Equations of Motion ---------- 15

II. PROBLEM STATEMENT ---------- 23

III. PROCEDURE AND DATA ---------- 24

A. PHASE I DATA BASE ---------- 24

1. Straight Runs ---------- 24

2. Straight Runs with Simple Waves -------- 26

B. PHASE II TURNING DATA ---------- 37

1. Constant Flat Turns ---------- 37

2. The Roll Phenomenon for the 40 Knot Turns ---------- 38

3. Turns with Simple Waves ---------- 44

IV. DISCUSSION/EVALUATION OF DATA AND PROCEDURE ---- 53

A. PHASE I DATA BASE ---------- 54

1. Straight Runs ---------- 54

2. Straight Runs with Waves ---------- 54

B. PHASE II TURNING DATA ---------- 57

1. Calm Condition Turns ---------- 57

2. The Roll Phenomenon of the 40 Knot Turns ---------- 58

3. Turns with Simple Waves ---------- 59

V. CONCLUSIONS ---------- 61

A. TURNING CHARACTERISTICS ---------- 61

B. RECOMMENDATIONS FOR FUTURE STUDY ---------- 62

APPENDIX A. FIGURES ---------- 64

COMPUTER PROGRAM ---------- 90

LIST OF REFERENCES ---------- 141

INITIAL DISTRIBUTION LIST ---------- 142

FORM DD 1473 ---------- 144

LIST OF TABLES

I.	CAB/SES Incon Data Options	16
II.	Initialization Values	25
III.	Initial Wave Encounter Period	27
IV.	Beam Wave Simulations	32
V.	Final Time Simulation Speed	39
VI.	Average Final Roll Angle	39
VII.	Final Yaw Angle	40
VIII.	Average Yaw Rate	40
IX.	Average Pitch Angle	41
X.	Average Turn Radii	41
XI.	Forty Knot Turn Roll Data in Degrees	43
XII.	Summation of Principal Roll Producing Moments	45
XIII.	Turning Data for 40 Knot Turns with Waves	48
XIV.	Maxima/Minima Summary for Turns with Waves	51

LIST OF DRAWINGS

1. Forty Knot Turns: Roll Angle Versus Time --------- 64

2. Forty Knot Turns: Pitch Angle Versus Time -------- 65

3. Forty Knot Turns: Yaw Angle Versus Time ---------- 66

4. Eighty-Five Knot Turns: Roll Angle Versus Time --- 67

5. Eighty-Five Knot Turns: Pitch Angle Versus Time -- 68

6. Eighty-Five Knot Turns: Yaw Angle Versus Time ---- 69

7. One Hundred Knot Turns: Roll Angle Versus Time --- 70

8. One Hundred Knot Turns: Pitch Angle Versus Time -- 71

9. One Hundred Knot Turns: Yaw Angle Versus Time ---- 72

10. Forty Knot Turns: Turn Rate Versus Time ---------- 73

11. Forty Knot Turns: Summation of Axial Forces Versus Time ---------- 74

12. Forty Knot Turns: Summation of Lateral Forces Versus Time ---------- 75

13. Forty Knot Turns: Summation of Vertical Forces Versus Time ---------- 76

14. Forty Knot Turns: Summation of Roll Producing Moments Versus Time ---------- 77

15. Forty Knot Turns: Summation of Pitch Producing Moments Versus Time ---------- 78

16. Forty Knot Turns: Summation of Yaw Producing Moments Versus Time ---------- 79

17. Forty Knot Straight Run: Wave Amplitude Versus Time ---------- 80

18. Forty Knot Straight Run: Roll Angle Versus Time -- 81

19. Forty Knot Straight Run: Pitch Angle Versus Time - 82

20. Forty Knot Straight Run with Waves: Summation of Roll Producing Mements Versus Time ---------- 83

21. Forty Knot Straight Run with Waves: Summation of Pitch Producing Moments Versus Time ---------- 84

22. Forty Knot Turns: Wave Force x-Direction Versus Time ---------- 85

23. Forty Knot Turns with Waves: Wave Amplitude Versus Time ---------- 86

24. Forty Knot Turn Comparison with and without Waves: Roll Versus Time ---------- 87

25. Forty Knot Turn Comparison with and without Waves: Pitch Versus Time ---------- 88

26. Forty Knot Turn Comparison with and without Waves: Horizontal Displacement ---------- 89

TABLE OF SYMBOLS

a	wave amplitude
b	beam
d	draft
F	force
F_N	Froude number
G	gravitational constant
h	height
h_x	moment of momentum about the x-axis
h_y	moment of momentum about y-axis
h_z	moment of momentum about z-axis
I_{xx}	mass moment of inertia about x-axis
I_{xz}	mass product of inertia in x-z plane
I_{yy}	mass moment of inertia about y-axis
I_{zz}	mass moment of inertia about z-axis
K	roll moment
l	length
m	mass
M	pitch moment
N	yaw moment
P	roll angular velocity
P_a	atmospheric pressure
P_b	bubble pressure
Q	pitch angular velocity
R	yaw angular velocity
R_e	Reynolds number

T	thrust, also tangential force
U	longitudinal velocity
V	lateral velocity
W	vertical velocity
x	horizontal distance in direction of forward motion
X	longitudinal force
y	horizontal distance directed to starboard
Y	lateral force
z	vertical distance directed downward, also heave displacement
Z_s	vertical distance from keel to center of gravity
Z	vertical force
β	angle between wave direction and inertial x-axis
γ	angle between wave direction and craft x-axis
δ	deflection angle
η	wave elevation relative to calm water
θ	pitch angle, positive bow up
λ	wave length
ρ	mass density
ϕ	roll angle, positive port side up
ψ	yaw angle, positive turn to starboard
ω	frequency

I. INTRODUCTION

A. CAB/SES DEVELOPMENT

The very latest design in displacement ships still manage to operate very inefficiently in the 40-knot-plus range. In fact the state-of-the-art in hull design peaked in the early part of this century. Ship designers have realized all along that ordinary displacement vessels sacrificed much efficiency for added thrust at speeds in the 40 knot range due to hydrodynamic drag. Propulsive thrust required increases approximately as the square of the desired velocity. To bridge this 40 knot gap, naval architects turned toward the surface effect ships (SES). Hovercraft, hydrofoil, air cushion vehicles (ACV), ground effects machines (GEM), and captured air bubble (CAB) craft all come under this generic grouping. A SES is basically any ocean going or amphibian craft which has the capability to operate in the air/water interface, thereby greatly reducing hydrodynamic drag. This study utilizes the CAB; in particular, the BELL 100B CAB/SES.

The CAB was chosen over other SES due to projected state-of-the-art feasibility for high speed and sea keeping capabilities. Whereas hydrofoils and ACV's are size limited, the CAB is not. The CAB is mainly supported by an air bubble enclosed in the hard structure of a deck, two sidewalls, port and starboard, and flexible seals at the bow and stern. The air bubble is provided by a blower fan

system which provides enough pressure to support and lift the craft. Unlike the ACV cousin, the CAB retains its air pressure with the exception of leakage and occasional venting in higher sea states and maneuvers. The craft reacts much like a displacement craft when not supported on the bubble but maneuvering is extremely sluggish. Propulsion in several CAB/SES already built has been either waterjets or supercavitating propellers.

When "on-the-bubble", there is a pocket or depression in the water equivalent to the gross displacement minus that part of the displacement which is being supported by the sidewalls and seals. As the craft increases speed and moves forward so too does the depression. This causes the same type of waves as a displacement hull. As acceleration continues, the CAB overrides the forward portion of the depression. This is called the secondary hump and a bow-up trim is obtained. Continuing acceleration causes the depression to slip aft under the stern seal so that a smooth flow results. Hump speed has been surpassed, wave drag and skin friction drag have been significantly diminished, and the drag versus velocity curve decreases to values well below drag experienced by displacement vessels.

Over the past few years a joint research program has been carried out by the Navy and the Maritime Administration under the heading of Joint Surface Effects Ship Project Office (JSESPO). Presently that office is known as SESPO since the project is now sponsored by the Navy alone.

Several craft have since been designed, built, and tested. Among these are the XR-3, which is presently undergoing further research and evaluation at the Naval Postgraduate School in Monterey, California. Two 100 ton craft, the Aerojet General 100-A, propelled by a gas turbine water jet, and the Bell 100-B, a supercavitating propeller driven craft, are also undergoing evaluation by the SESPO. The ultimate projection of this program is to provide a CAB/SES in the multithousand ton class with cruise speeds from 80 to 100 knots.

The next step the project is expected to take is construction of a CAB/SES in the 2000 ton range. However, there are presently many questions such as seakeeping ability, safety, and dynamic behavior, which must be answered. Of the several methods for answering questions such as these, the most expensive would be to construct the full size prototype. On the other hand, towing tank model trials could be run, but probably the most effective method would be a computer simulation. In the long run the computer simulation data would have to be corroborated by empirical data. If the simulation were exceptionally good or at least a close approximation perhaps millions of dollars and many manhours could be saved. In the case of the CAB/SES the state-of-the-art rests in the two 100 ton craft already built. Instead of immediately building a 2000 ton craft based upon minimal data already obtained, Oceanics Incorporated was contracted to provide a computer simulation, for

the loads and motion study, see computer program section for the Bell 100B, with the following overall objectives:

1. To provide a computerized form of the six degree of freedom equations for SES craft that will yield time domain outputs of motions for the on-bubble mode of operation.
2. To determine the motions of specified SES configurations with special reference to human habitability, platform requirements (for military or commercial applications) and maneuvering requirements for the on-bubble mode of operation.
3. To establish a mathematical model for predicting maximum wave induced bending moments, both longitudinal and transverse, on SES craft to provide techniques that would yield slamming response for the on-bubble mode of operation.
4. To determine the stability derivatives in the vertical plane from measured data of the vertical plane motions of existing SES craft in a random seaway.[1]

Direct comparison of simulated data with experimental data should then provide a reasonable measure of the accuracy of the simulation. The next logical step is to convert the 100B program to simulate a 2000 ton craft.

B. BELL 100B CAB/SES PROGRAM

1. Simulation Statistics

All statistics given were held constant throughout the problem but may be modified. Parameters listed as variable were in fact varied throughout the procedure.

Total Craft Weight: 209,999.3 lbs

Center of Gravity:
Longitudinal (ft fwd. Transom): 33.09 ft
Vertical (ft above keel): 7.09 ft

---

[1] Kaplan, Paul, James Bentson, and Theodore P. Sargent, A Study of Surface Effect Ship (SES) Craft Loads and Motions, Part I - Equations of Motion of SES Craft with Six Degrees of Freedom, p. 2, prepared for Department of the Navy Surface Effect Ships Project Office, Contract No. C-1-35055, August 1971.

Total Craft length: 72 ft

Total Craft width: 33.8 ft (port and starboard sidewalls)

Ventral Fins: 3 ft by 3 ft

Plenum:
- Length waterline: 65.31 ft
- Length deck: 65.31 ft
- Width waterline: 31.16 ft
- Width deck: 28.00 ft
- Height average: 6.17 ft

Propulsion: Twin screws variable thrust

Steering: Twin rudders
- Turn Rate: Variable
- Maximum: Variable

Speeds: Variable

Fans:
- Bowseal: 2
- Sternseal: 2

2. Description of Program

The Bell 100B computer simulation is a Fortran IV program primarily designed to calculate time histories of motions and loads of a surface effect ship, operating in the on-the-bubble mode in a seaway in six degrees of freedom. The program is of modular form in that each major element of the craft has its own subprogram, 18 in all. This feature enables the programmer to make a wide range of parametric changes by simply changing input data. Additionally, this modular format facilitates changes or additions to any part of the program.

For any given program run, the main program calls the input and initialization subroutine INCON. The program then calculates the motion time histories by calling the

various modular subroutines for as many time increments as specified to complete the test case. During the calculations, the subroutines will, if requested, output variables selected by print option switches at desired print intervals.

Reference (1), the users manual, contains a breakdown on the contents of each subroutine. However, since the all important input data is handled by INCON, INCON will be discussed. INCON is composed of 19 separate blocks. Within each block there are one or more options or option control tags. Note in Table I, some of the options are listed as not required. The other options, those required, are considered to be the basic or specific data options without which the program will not run.

The original program's output occurred on a print time basis dependent on which print option switches were utilized. Additionally in the original program, the user could request print options which produced vertical and lateral plane summaries. See the computer program below as modified for this study.

3. Formulation of State Equations of Motion

The equations of motion utilized by the simulation are formulated in terms of the various force or moment contributing elements.

$$F_{Total} = \sum_{i=1}^{n} F_i \qquad (1)$$

Table I. CAB/SES Incon Data Options

BLOCK NUMBER	OPTION	REQUIRED	DESCRIPTION
001	01	Yes	Timing information
	02	No	Print options
	03	Yes	Integrators and error tolerances
	04	No	Summary prints
	05	No	Motion option switches
002	01	Yes*	Summary mass properties
	02	Yes*	Discrete mass properties
003	00	Yes	Craft geometric input
004	01	Yes	Sidewall input
	02	Yes	Appendage input
005	00	Yes	Sternseal input
006	00	Yes	Bowseal input
007	01	Yes	Plenum geometry
	02	Yes	Froude number input
008	01	Yes	Propulsion input
	02	No	Engine out input
009	01	Yes	Rudder input
	02	No	Rudder motion input
010	00	Yes	Aerodynamic input
011	01	No	Waves; amplitude vs. frequency
	02	No	Waves; amplitude vs. wave length
012	00	Yes	Initial condition
013	00	Yes	End of case indicator
014	00	Yes	End of run indicator
015	01	No	Shears and moments
	02	No	Shears and moments
	03	No	Shears and moments
016	Not Used		
017	Not Used		
018	00	No	Case title card
019	01	Yes	Bowseal fans
	02	Yes	Cushions fans
	03	Yes	Sternseal fans

*either but not both of these options

$$F_i = F_{bubble_i} + F_{sidewalls_i} + F_{bow\ seal_i} + F_{rudder_i}$$
$$+ F_{propulsion_i} + F_{aerodynamic_i} + F_{waves_i}$$
$$+ F_{stern\ seal_i} + F_{gravitational_i} \qquad (2)$$

where F represents a moment or a force and i represents a particular component such as in the lateral direction or around the lateral axis.

The craft's trajectory is referred to an inertial reference frame, a right handed cartesian coordinate system. Thus, x_o, y_o, and z_o show the trajectory with the craft's center of gravity at time t = 0 as the point (0,0,0). Roll (ϕ), pitch (θ), and yaw (ψ) angles are also referenced to this inertial coordinate system. Displacements toward the bow are considered as in the positive x_o direction; displacements to starboard are considered as positive in the y_o direction; displacements vertically down from the center of gravity are considered to be in the positive z_o direction; yaw (ψ) is positive with a turn to starboard; roll is positive with a heeling motion to starboard; and a bow up attitude is a positive pitch angle. Normal ship's motions including the CAB/SES have small values of pitch (θ) and roll (ϕ). The main angle indicating the orientation of the craft relative to the inertial frame is yaw angle (ψ) which may have a large range if maneuveuring occurs. Motion

in the z_o direction, heave, will also be greatly limited. Since roll, pitch and heave values remain relatively limited in magnitude, overall complexity in simulating hydrostatic and hydrodynamic forces and moments is greatly reduced.

The axis system describing the CAB/SES is assumed to translate with the craft through its trajectory. The craft's axis system is also a right handed cartesian coordinate system with its origin at the center of gravity. The vector relationship between the craft's axes and the inertial reference frame are given by:

$$\begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

where the coordinate axis in capital letters indicate vector quantities in the respective directions.

Waves are also orientated with these two reference systems; the inertial frame to determine the wave properties and the craft's reference frame to determine the wave effect on the craft itself. Waves are assumed to be propagating in the direction defined by β, where β is the angle formed by the normal to the wave crests in the direction of propagation and the positive x_o axis. Waves propagate at an angle γ relative to the ship where γ is defined by:

$$\gamma = \beta - \psi \qquad (4)$$

For example, if the craft were not maneuvering, γ would equal β, since ψ equals zero (0), and for waves coming from the bow γ would equal 180 degrees.

Considering a linear velocity $\overline{V}_E$, a vector quantity with components in the x, y, and z directions,

$$\overline{V}_E = iU + jV + kW \tag{5}$$

then,

$$\overline{F}_E = i\,\Sigma F_x + j\,\Sigma F_y + k\,\Sigma F_z$$

$$= \frac{d}{dt}\, m(iU + jV + kW) \tag{6}$$

Application of Newton's laws of motion with assumption of constant moments of inertia equal to rigid body values and small angle analysis leads to:

Axial Force

$$X = \Sigma F_x = \frac{d}{dt}\,(mU) - mVR + mWQ \tag{7}$$

Lateral Force

$$Y = \Sigma F_y = \frac{d}{dt}\,(mV) + mUR - mWP \tag{8}$$

Normal Force

$$Z = \Sigma F_z = \frac{d}{dt}\,(mW) - mUQ + mVP \tag{9}$$

Rolling Moment

$$K = \Sigma M_x = \frac{dh_x}{dt} = I_{xx}\dot{P} + (I_{zz} - I_{yy})QR - (\dot{R} + PQ)I_{xz} + (R^2 - Q^2)I_{yz} + (PR - \dot{Q})I_{xy} \quad (10)$$

Pitching Moment

$$M = \Sigma M_y = \frac{dh_y}{dt} = I_{yy}\dot{Q} + (I_{xx} - I_{zz})RP - (\dot{P} + QR)I_{xy} + (P^2 - R^2)I_{zx} + (PQ - \dot{R})I_{yz} \quad (11)$$

Yawing Moment

$$N = \Sigma N_z = \frac{dh_z}{dt} = I_{zz}\dot{R} + (I_{yy} - I_{xx})PQ - (\dot{Q} + RP)I_{yz} + (Q^2 - P^2)I_{xy} + (RQ - \dot{P})I_{zx} \quad (12)$$

where

$$\begin{bmatrix} h_x \\ h_y \\ h_z \end{bmatrix} = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix} \begin{bmatrix} P \\ Q \\ R \end{bmatrix} \quad (13)$$

and U, V, and W are linear velocities along and P, Q, and R are angular velocities about the x, y, and z axes respectively. Also associated with these equations are the kinematic relations

$$\dot{\phi} = P + \dot{\psi}\sin\theta \quad (14)$$

$$\dot{\theta} = \frac{Q - \dot{\psi}\cos\theta \sin\phi}{\cos\theta} \quad (15)$$

$$\dot{\psi} = \frac{R + \theta\sin\phi}{\cos\theta \cos\phi} \quad (16)$$

Next, consider the nonlinear inertial coupling as indicated in Equations (10) and (11). When the above equations were in the process of being formulated for the computer simulation, a computational approach was carried out using analog computers to determine the significance of nonlinear inertial coupling using the nonlinear model of inertial coupling terms. Results showed negligible difference in responses and the decision was made to simplify the equations of motion by deleting all nonlinear inertial coupling terms. Thus, for formulation into digital computer program, Equations (7) through (12) may be simplified and written:

$$\begin{bmatrix} U \\ V \\ W \\ P \\ Q \\ R \end{bmatrix} = \begin{bmatrix} m & 0 & 0 & 0 & 0 & 0 \\ 0 & m & 0 & 0 & 0 & 0 \\ 0 & 0 & m & 0 & 0 & 0 \\ 0 & 0 & 0 & I_{xx} & 0 & -I_{xz} \\ 0 & 0 & 0 & 0 & I_{yy} & 0 \\ 0 & 0 & 0 & -I_{xz} & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} X \\ Y - MUR \\ Z \\ K \\ M \\ N \end{bmatrix} \tag{17}$$

The above form of the state equations allows establishing the equations of motion in state variable form as a set of first order differential equations. $\dot{W}$, $\dot{P}$, and $\dot{Q}$ are augmented by the simplified relationships from equations

$$W = \dot{Z} \tag{18}$$

$$P = \dot{\phi} \tag{19}$$

$$Q = \dot{\theta} \tag{20}$$

thus introducing additional state variables. These states may then be transposed back to the inertial axes by use of Equations (3), and trajectories are determined through simple integration procedures.

II. PROBLEM STATEMENT

The BELL 100B is assumed to be modelled by the computer program created by OCEANICS. The computer program is to be used to determine theoretically, the craft's turning characteristics in calm water and in simple waves. Turning characteristics relative to roll, pitch, yaw, and their rates of change are expected to compare favorably with available empirical data.

III. PROCEDURE AND DATA

A. PHASE I DATA BASE

Prior to development of the above problem statement and acquiring the necessary data, an initialized data base had to be established and trends, where trends existed, had to be noted. The data obtained in this study were obtained using the IBM 360/67 computer at the W. R. Church Computer Facility at the Naval Postgraduate School.

1. Straight Runs

Through this part of the initialization phase, longitudinal speeds (U) of 40 knots through 105 knots inclusive at 5 knot increments were used. Straight runs of 50 seconds duration were made at each speed. Velocity was set at a constant value and thrust was allowed to vary as a function of surge only. For all speeds, except 95, 100, and 105 knots, steady state values of thrust (T), pitch (θ), and draft (d) were recorded and used as initialization values for a steady state run of 10 seconds. For the ten second run, all values remained constant; see Table II.

Speeds of 95, 100, and 105 knots in actuality did not reach a steady state at the 50 second mark as did the other speeds. However, values of pitch, draft, and thrust were averaged over the last 20 second period. These values were in turn used in the 10 second run which again did not reach steady state. Thus, the values in Table II for these higher speeds are actually average values. Plenum pressure

Table II. Initialization Values

ORDERED SPEED (KTS)	ONE ENGINE THRUST (LB)	DRAFT (FT)	PITCH (DEG)
40	5091.5	1.272	.23
45	5490.2	1.223	.26
50	6002.4	1.166	.28
55	6589.3	1.103	.31
60	7221.3	1.003	.33
65	7872.8	.956	.35
70	8521.0	.874	.36
75	9147.1	.786	.38
80	9731.4	.694	.39
85	10254.3	.598	.39
90	10697.8	.498	.40
95*	10839.1	.362	.57
100*	11646.8	.337	.60
105*	12631.5	.322	.61

*Average Values

was held at a constant 92.8 pounds per square inch for all runs. All succeeding simulation runs utilized these initialized values, thus forming a steady state reference point for system perturbations.

2. Straight Runs with Simple Waves

To further the data basis for turning maneuvers, it was decided to make straight trial runs with varying wavelength (λ), wave amplitude (a), and speed (U). Initial runs were conducted with wave fronts coming from three different relative directions, β = 000° (astern waves), β = 090° (port beam waves), and β = 180° (bow waves). For each of these directions, speed (U) was varied (U = 40,50,60,70,85,90 and 100 knots). Wave amplitude was set to a = 0.5 ft and wavelength λ = 720 ft. Since this wavelength was ten craft lengths and the amplitude was relatively small, the situation approached that of an infinite wavelength. The initial conditions were set in accordance with data noted above.

Table III shows the wave encounter period as experienced by the craft. The program computes initial encounter frequency in INCON as follows:

$$\omega_{encounter} = 2\pi(g\lambda/2\pi)^{\frac{1}{2}} - (u \cos\beta)/\lambda \ . \qquad (21)$$

Negative encounter periods occur when the craft overtakes the waves in a following sea. For waves from the bow and the stern, no motion was noted in the lateral plane. Pitch angle (θ) did oscillate in both cases at the approximate

Table III. Initial Wave Encounter Period

SPEED (knots)	BOW WAVES (sec)	STERN WAVES (sec)	BEAM WAVES (sec)
40	5.613	-105.26	11.859
50	4.960	- 30.342	11.859
60	4.443	- 17.726	11.859
70	4.024	- 12.520	11.859
85	3.525	- 8.691	11.859
90	3.385	- 8.887	11.859
100	3.136	- 6.656	11.859

wave encounter period with slight phase difference. These trends deviated slightly at U = 100 knots. At 100 knots, still no motion was noted in the lateral plane. With the encounter period reduced to 2.136 seconds, venting, presence of air entry gaps along the sidewall, was noted at the center of gravity by the fact that draft was shown to be negative at various, though seemingly non-frequency related, intervals. The sidewalls of the craft did not completely leave the water as noted by the fact that the plenum gauge pressure did not fall below zero as was seen in later runs.

Also noted in these runs where perturbation forces acted only in the vertical plane, was the fact that the relative difference between the accelerations of bow and the center of gravity never varied by more than 0.05 G in the 'worst case' runs of U = 100 knots. In spite of this small variance, the craft's attitude in the vertical plane, θ, rose and fell with the rise and fall of the wave encounter period with both bow and stern waves.

For waves from the port beam, the wave encounter frequency was the same encounter frequency as would be experienced if the craft were stationary. The bow and stern waves caused the initial velocity of U = 100 knots, 168.89 ft/sec, to decrease to U = 161.69 ft/sec and U = 166.41 ft/sec respectively by time t = 25 seconds. However, the beam waves produced only a slight oscillation about a nominal drop in speed of about .4 ft/sec. Outputs for the beam wave case which vary significantly from the bow and

stern wave cases were pitch, roll, yaw rate, and displacement along the y-axis. It was interesting to note that an oscillation in pitch angle was produced when there were no explicit perturbation forces either in the z-direction or around the y-axis. The oscillation period appeared to be approximately that of the wave encounter period but slightly out of phase by one to two seconds. These oscillations were smaller than the oscillations noted in cases with bow and stern waves.

Further compilation of data from the beam wave case showed that draft measurements oscillated at approximately the same frequency as wave encounter frequency but were 180 degrees out of phase when considering maximum amplitudes. Roll angle (ϕ) and yaw rate (R) also showed a marked periodicity with respect to the encounter frequency. However, as speed (U) was increased this relationship to the encounter frequency seemed to diminish. Roll angle showed no discernible frequency whatsoever at 100 knots.

The next step taken was to reduce the wavelength of the simple wave. In the same manner as explained above, with seas from three directions, computer runs were made using a wavelength λ = 360 feet or five craft lengths, with speeds U = 40, 50, 60, 70, 85, 90, and 100 knots. Results with the following exceptions were approximately the same as the above case: even at the 100 knot level the pitch angle showed a definite relationship to the wave encounter frequency oscillations; venting did occur for the bow waves

and the stern waves but the excursion in plenum gauge pressure was much greater in both cases; differences in bow and center of mass accelerations were greater; longitudinal velocity dropped off more in both the bow and stern seas case, but longitudinal velocity for the port beam seas show a slight but almost constant decrease, vice an oscillation over the 25 second problem period; maximum pitch excursions for the beam seas were about the same in both cases, ±0.5 degrees, but this excursion was significantly less for the bow and stern sea cases.

The next step in setting the basis was to determine parameter variances over a wide range of representative values. To accomplish this, it was decided to utilize wavelength values of relative craft lengths. Thus, wavelength (λ) was varied as one-half a craft length, λ = 36 feet, one craft length, λ = 72 feet, two craft lengths, λ = 144 feet, and three craft lengths, λ = 216 feet. In that the plenum average height is slightly over six feet and that drafts of 1.5 feet have been measured with only a 0.5 foot wave amplitude, wave amplitudes of a = 0.5, 1.0, and 2.0 feet were chosen as representative values. Furthermore, it was noted that in the program, the input wave amplitude "a" was in fact an amplitude, but when considering effects of sea waves, the peak to peak value, the crest to trough value or the wave height is the measurement usually considered. In other words, the above values of wave amplitudes chosen have heights of 1, 2, and 4 feet

respectively. The latter height leaves little room for heave mctions and therefore, when water contacted the top of the plenum, whenever fan horsepower went negative, or whenever the plenum gauge pressure went negative, the run was considered to be aborted.

The same procedure, as followed for the above cases, where λ = 720 feet and λ = 360 feet, was utilized for the varying wavelength and wave amplitudes. For each value of wave amplitude, a = 0.5, 1.0, and 2.0, a total of 84 simulations were run, varying wavelength, wave direction, and speed. An example of the data collected is shown for beam waves, in Table IV. Data for bow and stern waves were also collected, but the data were omitted due to later usage of beam waves as an initial condition for turns.

Behavior of the CAB/SES in the above wave conditions was best compared by categorizing the waves by wave direction and not by wave amplitude. The most "well behaved" of all the wave directions was the beam wave. Well behaved in this case means that of all the wave directions, beam waves provided fewer run abortions than bow and stern waves. Of the 36 runs, documented in Table IV, only three runs were aborted due to water contact with the plenum deck. The bow and stern waves had twelve aborted runs each.

For bow waves pitch angle maximum excursion was greatest for the longer wavelength, lower speeds, and higher wave amplitudes. The maximum pitch for bow waves was recorded at t = 20.5 seconds of the run using the wavelength

Table IV. Beam Wave Simulations

SIMULATION a	/ λ	/ β	/ U	PITCH ANGLE MAX	/ Δθ	/ PHASE#	ROLL ANGLE MAX	/ Δφ	/ PHASE#	YAW ANGLE RATE MAX	/Δψ	/ PHASE#
.5	216	090	40	.35	.19	0.5	1.27	2.25	1.5-2.0	.304	.55	3.0-3.5
			60	.43	.18	0.5	1.18	2.31	1.5-2.0	.395	.70	3.0-3.5
			100	.81	.60	0.5	.75	1.30	1.5-2.0	.321	.55	3.0-3.5
.5	144	090	40	.65	.81	0.5	2.25	4.39	2.5-3.0	.607	1.1	2.5-3.0
			60	.50	.30	0.5	1.83	3.60	2.5-3.0	.615	1.085	2.5-3.0
			100	.77	.60	0.5	1.02	1.90	2.5-3.0	.543	.90	2.5-3.0
.5	072	090	40	.65	.81	0.5-1.0	6.56	12.60	0.5-1.0	1.462	1.91	1.5-2.0
			60	.70	.76	0.5	5.17	10.24	0.5-1.0	1.439	2.70	1.5-2.0
			100	.79	.75	0.0	2.65	5.91	0.5-1.0	1.0	1.92	1.5-2.0
.5	36	090	40	.69	.90	1.0	.69	1.45	1.0-1.5	.16	.32	1.0-1.5
			60	.86	.98	0.5	.58	1.11	1.0-1.5	.117	.219	.5
			100	.86	1.0	0.0	.75	1.30	1.0-1.5	.347	.664	1.0

Table IV. Beam Wave Simulations (Continued)

SIMULATION a	λ	β	U	PITCH ANGLE MAX	Δθ	PHASE#	ROLL ANGLE MAX	Δφ	PHASE#	YAW ANGLE RATE MAX	Δψ	PHASE#
1	144	090	40	.62	.87	0.5	4.33	8.32	1.0	1.097	2.11	2.0
			60	.69	.76	0.5	3.53	6.18	1.0-1.5	1.190	2.04	1.5
			100	.83	.84	0.0	2.79	4.00	1.0	1.358	2.12	1.0
1	72	090	40	1.48	2.82	2.0-2.5	12.83	23.50	1.5	2.511	4.6	2.0
			60	.64	1.00	1.0-1.5	9.67	18.74	1.0-1.5	2.194	4.1	1.5-2.0
			100	.91	1.12	0.5	5.55	10.85	1.0-1.5	1.734	3.4	1.0
1	36	090	40	1.06	1.80	1.0	1.51	2.52	1.5	.357	.683	0.5
			60	1.23	2.00	0.5-1.0	1.33	2.53	1.0	.261	.495	0.5
			100	1.14	1.83	0.0-0.5	1.36	2.37	1.0-1.5	.485	.875	0.5-1.0
2	216	090	40	.82	1.14	0.5	6.44	11.85	0.5-1.0	1.600	3.20	1.5
			60	.85	.98	0.5	5.34	9.78	1.0	2.047	2.12	1.0-1.5
			100	1.17	1.43	0.0	4.09	7.00	0.5	2.373	3.373	0.5
2	144	090	40	.89	1.36	0.5	6.65	11.69	1.0	1.600	2.91	2.0
			60	.86	1.57	0.5	6.59	12.20	1.0	1.770	3.00	1.0
			100	1.25	1.75	0.0	5.35	9.10	1.0	2.189	3.60	1.0

Table IV. Beam Wave Simulations (Continued)

SIMULATION a	/ λ	/ β	/ ↷U	PITCH ANGLE MAX	/ Δθ	/ PHASE	ROLL ANGLE MAX	/ Δφ	/ PHASE	YAW ANGLE RATE MAX	/ Δψ	/ PHASE
*2	72	090	40	3.26	4.51	0.0	20.00	38.82	2.5-3.0	3.80	7.4	2.50-3.0
*			60	3.03	5.60	0.5	16.92	31.95	1.5-2.0	3.524	6.00	1.5-2.0
			100	2.24	3.75	0.0	12.34	22.45	1.5-2.0	2.925	5.07	1.0-1.5
*2	36	090	40	1.35	2.28	1.0	4.92	9.66	1.5	1.493	2.76	0.5
			60	1.29	2.28	0.5-1.0	3.12	7.02	1.5	1.354	2.659	0.5
			100	1.35	2.19	0.5	2.47	4.70	1.5	1.084	2.0	0.5

* Simulations aborted due to water contact with plenum deck.

\# Phase indicates phase lag in seconds from wave encounter frequency.

λ = 216 feet and amplitude a = 2 feet at speed U = 40 knots. The frequency of oscillation of the pitch angle seemed to correspond roughly to the wave encounter frequency. However, in that print output was a one-half second interval, it was difficult ot determine phase delay times, and for shorter encounter periods it was impossible to determine any phase or frequency relationship at all. Starting with the one foot amplitude waves and continuing through, no pattern could be determined with gauge pressure fluctuation for the bow waves with the possible exception that as speeds increased, maximum-minimum fluctuations increased. This was also the case for stern waves. Maximum acceleration, pitch producing, differentials appeared between the center of gravity and the bow increasing with wavelength until λ = 144 feet and then dropped off considerably for smaller wavelengths. Interestingly final speeds of runs which were not aborted hit a low point at λ = 144 feet.

Stern waves, aside from producing the same number of aborted runs as bow waves, produced decidedly more adverse reactions in the craft. For all wave amplitude groupings, λ = 144 seemed to affect the craft more adversely than any other wavelength. Maximum pitch and pitch excursion were produced with wave amplitudes of a = 0.5 and 1.0 feet and speeds of 40 knots. Additionally, the most violent plenum pressure gauge fluctuations, bow and center of mass accelerations differences, and speed loss were also noted

for λ = 144 feet. As one would expect, there were no yawing or roll moments from either the bow or stern waves. Aborted runs due to negative fan horsepower seemed to occur whenever gauge pressures went above 120 pounds per square foot.

Results for the beam waves are presented in Table IV. Generally speaking, maximum pitch and pitch excursions increased with speed amplitude and decreasing wavelength with only two exceptions for non-aborted runs during the a = 2 foot simulations. The frequency of oscillation seemed to match wave encounter frequency in every case with little, or in some cases, seemingly no phase difference. Acceleration variances between the bow and the center of mass were considerably less than values noted for either bow or stern wave cases, as were plenum gauge pressure fluctuation extremes. The low point for final speed loss in most cases appeared at values of λ = 72 feet. The major difference between bow and stern waves and beam waves, for the non-maneuvering case, were the lateral component wave forces which produce roll and yaw moments. For the beam wave simulations, roll in every case decreased with speed. Also, values of roll increased up to λ = 72 feet and then dropped off at λ = 36 feet for cases where speed was held constant. Both yaw rate and roll frequencies of oscillation were related to encounter frequency with varying phase time lag. The yawing effect was noted to be considerably higher for higher amplitude waves and then dropped off within amplitude groupings when moving from λ = 72 feet to λ = 36 feet.

B. PHASE II TURNING DATA

1. Constant Flat Turns

To provide a wide basis for turning data speeds of U = 40, 50, 60, 70, 85, 90 and 100 knots were each simulated through turns of constant 5, 7.5, 10, 12.5, 15, 17.5, and 20 degree rudder. For each rudder used under each speed the problem was allowed to run on a straight course for two seconds prior to moving the rudder. Initial condition values as determined above were not varied. At the two second mark, the rudder was moved five degrees per second until the final rudder was reached. Thus, the final rudder angles were reached at times t = 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, and 6.0 seconds respectively for the above rudder angles. Figures 1 through 9 show roll, pitch, and yaw for representative speeds U = 40, 85, and 100 knots. In all cases the ordinate units were measured in degrees and the abscissa's units denoted problem time up to 25 seconds. To reduce confusion on the plots, only 5, 15, and 20 degree rudder values were plotted. For these turns it was noted that values of pitch and roll tended to oscillate about an average value. As time increased, the average value of roll/heel tended to decrease. This may be seen in Figures 1, 4, and 7, where the negative values of roll indicate a heeling motion to port for 5, 15, and 20 degree turns at 40, 85, and 100 knots. In the analysis of the yaw rate plot, Figure 10, yaw rate also oscillated around an average negative value, indicating

a turn to port. Yaw rate appears to be constant when considering the yaw versus time curves in Figures 3, 6, and 9.

In all cases, there was a steady decrease in speed throughout the 25 second turn problem; Table V. The more rudder used, the more final speed was down from the initial value. Average final roll angle, or heel, increased with increasing speed; Table VI. Yaw and yaw rate reacted in like manner but also increased with rudder angle as well; see Tables VII and VIII. Pitch angle was slightly more erratic. For 40 and 50 knot runs, final average pitch angle for five degree turns were slightly less than the initial condition steady state pitch angles. In both cases as rudder angle was increased, pitch angle decreased. For all other speeds, the five degree final average pitch angle was higher than the initial condition value for the corresponding speed. As larger rudder angles were used the final average pitch angles increased and then dropped off at rudder angles of 7.5 degrees for 60 knots and 85 knots, and dropped off at 10.0 degrees rudder for 70 knots and 100 knots; Table IX. Turning radii varied considerably for five degree rudders on a speed to speed basis. However, turning radii seemed not to be dependent upon speed for 15 degree and 20 degree rudders; Table X.

2. The Roll Phenomenum of the 40 Knot Turns

While plotting various turn data for the forty knot turns versus problem time, it was noted that values for roll

Table V. Final Time Simulation Speed (feet/second)

RUDDER ANGLE IN DEGREES	SPEED IN KNOTS						
	40	50	60	70	85	90	100
5	66.7	83.0	99.1	114.7	136.8	143.1	153.2
15	60.7	74.4	87.1	98.5	112.5	116.4	123.5
20	56.4	68.7	79.7	89.6	101.0	104.2	109.8

Table VI. Average Final Roll Angle (degrees)

RUDDER ANGLE IN DEGREES	SPEED IN KNOTS						
	40	50	60	70	85	90	100
5.0	.352	.593	.86	1.17	1.44	1.58	1.77
7.5	.469	.766	1.10	1.49	1.95	2.03	2.30
10.0	.541	.872	1.24	1.62	2.19	2.33	2.50
12.5	.577	.897	1.25	1.62	2.17	2.34	2.63
15.0	.580	.871	1.20	1.54	2.03	2.18	2.47
17.5	.547	.824	1.11	1.42	1.83	1.96	2.20
20.0	.496	.757	.97	1.23	1.60	1.71	1.90

Table VII. Final Yaw Angle (degrees)

RUDDER ANGLE IN DEGREES	SPEED IN KNOTS						
	40	50	60	70	80	90	100
5	16.4	20.5	23.3	26.3	28.9	29.9	33.0
15	53.7	64.8	75.3	84.6	97.8	101.0	109.0
20	70.6	85.3	99.0	111.4	129.6	134.5	145.5

Table VIII. Average Yaw Rate (degrees/second)

RUDDER ANGLE IN DEGREES	SPEED IN KNOTS						
	40	50	60	70	80	90	100
5.0	.6	.8	1.0	1.1	1.1	1.1	1.3
7.5	1.0	1.3	1.5	1.7	1.8	1.8	2.0
10.0	1.4	1.7	2.1	2.3	2.6	2.6	2.8
12.5	1.8	2.2	2.6	2.9	3.3	3.3	3.5
15.0	2.2	2.7	3.1	3.5	3.9	4.0	4.3
17.5	2.5	3.1	3.6	4.0	4.5	4.6	4.9
20.0	2.9	3.5	4.0	4.5	5.1	5.2	5.5

Table IX. Average Pitch Angle (degrees)

RUDDER ANGLE IN DEGREES	SPEED IN KNOTS						
	40	50	60	70	85	90	100
5	.220	.279	.340	.407	.603	.646	.673
7.5	.210	.276	.351	.440	.652	.728	.740
10.0	.197	.267	.350	.445	.590	.706	.787
12.5	.178	.250	.328	.428	.579	.626	.747
15.0	.154	.218	.298	.387	.526	.560	.658
17.5	.125	.177	.252	.326	.454	.489	.568
20.0	.095	.126	.206	.253	.363	.393	.455
Initial	.23	.28	.33	.36	.39	.40	.62

Table X. Average Turn Radii (feet)

RUDDER ANGLE IN DEGREES	SPEED IN KNOTS						
	40	50	60	70	85	90	100
5	5800	5850	6000	6100	6750	6720	6750
15	1590	1600	1620	1640	1640	1650	1660
20	1130	1120	1140	1130	1130	1140	1135

were not compatible with expected results; see Figure 1. The value of roll for the first positive cycle, roll to starboard, for five degrees was greater than the value of the twenty degree turn by about 0.8 degrees. Furthermore, throughout the rest of the simulation, the amplitude of the five degree rudder oscillation was substantially greater than the amplitude for the twenty degree rudder.

To gather data to explain this apparent phenomenom, initial results were first double checked both with smaller tolerances for the Runge-Kutta-Merson numerical integration technique and a constant step size; see computer program section. Results showed initial calculations to be correct. Next, values of roll were retabulated for rudder angles of five, fifteen and twenty degrees; Table XI. It was noted that the values for the fifteen degree rudder were the same point by point as the five degree rudder until time t = 3.5 seconds; the rudder had stopped moving for the five degree turn at time t = 3 seconds and time 3.5 seconds the rudder was still swinging for the fifteen degree rudder simulation. Likewise, the values of roll for the twenty degree turn were the same at time t = 5.5 seconds as the values for the fifteen degree turn.

The program was then modified, see the computer program section, to provide an optional output which included summations of axial forces (X), lateral forces (Y), vertical forces (Z), roll moments (K), pitch moments (M), and yaw moments (N); see Figures 11 through 16. Further modification

Table XI. Forty Knot Turn Roll Data

	RUDDER ANGLE IN DEGREES		
Time	Five	Fifteen	Twenty
2.0	0.0	0.0	0.0
2.5	.09	.09	.09
3.0	.52	.52	.52
3.5	1.07	1.18	1.18
4.0	1.07	1.61	1.61
4.5	.47	1.53	1.53
5.0	.26	1.05	1.05
5.5	.58	.48	.57
6.0	.27	0.0	.46
6.5	.42	.13	.69
7.0	1.02	.18	.83
7.5	1.15	.73	.68
8.0	.74	1.16	.43
8.5	.14	1.18	.31
9.0	.25	.84	.43
9.5	.20	.42	.70
10.0	.20	.23	.89
10.5	.68	.35	.85
11.0	.91	.64	.61
11.5	.77	.89	.39
12.0	.39	.91	.35
12.5	.05	.74	.50
13.0	.05	.52	.69
13.5	.13	.42	.77
14.0	.45	.48	.68
14.5	.69	.63	.51
15.0	.70	.74	.42
15.5	.51	.75	.45
16.0	.25	.66	.57
16.5	.10	.56	.66
17.0	.10	.52	.64
17.5	.32	.55	.55
18.0	.52	.62	.46
18.5	.61	.66	.45
19.0	.54	.66	.51
19.5	.38	.61	.58

was made to the basic program to provide the components of the roll moment (K). These include the bowseal, the sternseal, the rudder, the side walls and appendages, the propellers, the bubble, as well as components from wave and aerodynamic inputs. As above, with roll angles, the summation of moments about the x-axis were equal through time 3.0 seconds. At t = 3.5 seconds, the summation of moments for the five degree turn case jumped to over 44,000 ft. lb. where as the summation of moments was only about 14,000 ft. lb. for the twenty degree turn. See Table XII for precise tabulation results of times t = 2 seconds through t = 7 seconds for the summation of moments about the x-axis.

3. Turns with Simple Waves

The final steps of this procedure included determining what and how many simulation runs to make to insure valid data. Original intentions were to establish a field of various wave lengths, speeds, and wave amplitudes from all three wave directions as utilized in the above procedure. However, during those runs it was noted that the craft's reactions to parametric changes were highly dependent upon wave encounter frequency. The craft reacted in a much more seaworthy manner with beam waves. For higher velocities and amplitudes and smaller wavelengths, simulation runs were often aborted due to loss of plenum pressure, water contact with the deck of the plenum or due to negative plenum fan horsepower caused by high pressures within the plenum. It was noted that the craft will experience

Table XII. Summation of Principle Roll Producing Moments

Five Degree Rudder Simulation

TIME (sec)	M x (ft.lb.)	M rudder (ft.lb.)	M bubble (ft.lb.)	M sidewall (ft.lb.)	RUDDER (deg)
2.0	0.0	0.0	0.0	0.0	0.0
2.5	32,522.0	42,011.0	1700.0	10,359.	2.5
3.0	19,994.0	63,742.	4872.	48,782.	5.0
3.5	44,603.0	36,589.	20132.	91,491.	5.0
4.0	49,689.0	28,959.	20510	89,133.	5.0
4.5	10,847.0	29,719.	9673.	45,510.	5.0
5.0	29,839.0	32,491.	3517.	854.	5.0
5.5	45,134.0	35,127.	4501.	14,864.	5.0
6.0	28,444.0	37,465.	4676.	6,630.	5.0
6.5	5,060.0	39,503.	7010.	48,214.	5.0
7.0	32,804.0	40,868.	17522.	8 2,627.	5.0

Fifteen Degree Rudder Simulation

2.0	SAME AS ABOVE				0.0
2.5					2.5
3.0					5.0
3.5	14,672.	78,945.	21,788.	104,762	7.5
4.0	37,159.	95,386.	29,625.	147,688	10.0
4.5	28,570.	115,132.	28,287.	158,146	12.5
5.0	1,588.	138,015.	19,880.	146,565.	15.0
5.5	1,414.	120,520.	10,047.	124,223.	15.0
6.0	21,690.	119,312.	1,469.	98,770	15.0
6.5	30,961.	121,867.	1,458.	90,146.	15.0
7.0	18,247.	126,382.	3,159.	107,645.	15.0

Twenty Degree Rudder Simulation

2.0	SAME AS ABOVE				0.0
2.5					2.5
3.0					5.0
3.5					7.5
4.0					10.0
4.5					12.5
5.0	1,580.	162,916.			15.0
5.5	28,056	187,987.	11,594	140,705.	17.5
6.0	31,414.	170,725.	9,062.	101,486	20.0
6.5	12,522.	168,321.	13,316.	190,036.	20.0
7.0	21,524.	170,424.	14,910.	197,390.	20.0

NOTE: All moment producing elements are not included.

varying encounter frequencies with any initial wave direction utilized since wave encounter frequency is a function of wavelength, longitudinal velocity, and relative wave direction. For each simulation where the ship is maneuvering an instantaneous encounter frequency is determined. Thus, it was decided to start each problem with waves from the port beam, allow the craft to follow a straight course for the first two seconds and then put the rudder over at time t = 2 seconds with a rudder swing of five degrees per second as was done above for the flat turns. Again initialized data as determined in the early part of this procedure were used.

At this point another cecision had to be made in order to provide enough useable data. The original plan was to make sets of twelve computer runs for each of the speeds U = 40, 50, 60, 70, 85, 90, and 100 knots. Six-hundred-seventy two simulations averaging seven minutes each were nearly out of the question. On a second cut, it was decided to use each of the above speeds with eight runs. Each run consisted of seven cases with varying rudder angles of five degrees through twenty degrees in 2.5 degrees increments. The eight runs used various combinations of previously used wave amplitudes a = 0.5, 1.0, and 2.0 feet and wavelengths λ = 216, 144, 72, and 36 feet. For each group of runs, λ = 144, a = 2; λ = 72, a = 2; λ = 144, a = 1; and λ = 72, a = 1, was deleted. These values were deleted not only because of the computer time requirement, but also

due to the fact that these four sets provided repetitive values of wave amplitude to wavelength ratios:

$$\text{Max slope} = 360° \cdot \frac{a}{\lambda} \tag{22}$$

as determined in the subroutine INCON.

Table XIII is presented to show the format for data collected at all speeds. Particular turning maxima and minima are noted in Table XIV. The terms $\Delta\phi$ and $\Delta\theta$ in Table XIV are maximum roll and pitch excursions respectively. Maximum values were absolute values while the minimum values were the minimum of the maximum values of collected data. In general, roll seemed to increase with decreasing wavelength until λ = 36 feet. At this point roll values decreased significantly. In all cases, roll values were less for wavelengths of 36 feet than they were for wavelengths of 216 feet.

Pitch generally decreased from λ = 216 feet with decreasing wavelengths. Side slip angle, the angle formed by the direction of force summation and the ship's longitudinal axis, varied with increasing rudder angle. Rudder angles of five degrees, fifteen degrees, and twenty degrees corresponded to average side slip angles of 2.3, 5.8 and 7.3 degrees respectively. Yaw angle and yaw rate increased with increasing rudder angle and speed. Further observations not directly associated with turning data were gauge pressure readings and final speed relationships. Again, as with

Table XIII. Turning Data for Forty Knot Turns with Waves

SIMULATION U	a	λ	δ rud	PITCH ANGLE θ MAX	PITCH ANGLE Δθ MAX	ROLL ANGLE ø MAX	ROLL ANGLE Δø	YAW MAXIMA	YAW MINIMA	FINAL	AVERAGE SIDE SLIP
40	.5	216	5	.66	.91	1.82	3.05	1.1	.2	17.75	2.22
			15	1.59	1.76	2.01	2.93	3.8	1.4	55.89	5.95
			20	1.61	2.95	1.69	2.35	4.6	1.9	72.60	7.57
		144	5	1.27	2.21	3.79	6.82	1.6	1.8	18.37	2.3
			15	1.56	2.71	2.42	3.49	4.1	1.7	55.52	5.9
			20	1.14	2.45	2.44	3.01	4.8	2.5	72.53	7.5
		72	5	1.13	1.93	4.84	9.35	1.8	.2	18.59	2.3
			15	1.35	2.42	4.26	7.57	4.4	2.0	56.41	5.9
			20	1.26	2.42	4.27	7.24	4.0	2.7	73.75	7.5
		36	5	.58	.70	1.68	2.70	1.9	.55	17.36	2.3
			15	.58	.83	1.80	2.21	3.8	2.2	54.14	5.9
			20	.58	.86	1.80	2.11	4.7	2.9	71.40	7.5
	1.0	216	5	1.07	1.89	2.84	5.44	1.7	0.02	18,37	2.1
			15	3.09	5.95	2.99	5.27	4.8	1.1	62.92	5.5
			20	3.20	6.30	2.46	4.76	6.7	1.3	82.05	7.5

Table XIII. Turning Data for Forty Knot Turns with Waves
(Continued)

SIMULATION U / a / λ / δ rud				PITCH ANGLE θ MAX	PITCH ANGLE Δθ MAX	ROLL ANGLE Ø MAX	ROLL ANGLE ΔØ	YAW MAXIMA	YAW MINIMA	YAW FINAL	YAW AVERAGE SIDE SLIP
40	1.0	144	5	2.25	4.41	6.55	12.52	2.5	.2	25.17	5.5
			15	2.35	4.59	3.93	7.40	4.5	1.8	64.44	5.5
			20	2.73	5.25	4.01	7.47	6.3	2.4	83.76	7.0
		72	5	1.21	2.38	8.20	15.65	2.9	.36	23.24	2.1
			15	1.81	3.53	7.07	13.54	5.3	2.0	65.25	5.6
			20	1.99	3.72	6.67	13.0	6.3	2.5	83.59	7.2
		36	5	.80	1.3	2.30	4.20	2.0	0.3	17.69	2.2
			15	.77	1.46	2.39	3.25	4.0	2.1	56.41	5.8
			20	.79	1.55	2.56	4.19	5.2	3.0	76.10	7.25
40	2.0	216	5	1.84	3.6	7.39	13.67	3.2	.5	23.10	3.65/0.8
			15	4.83	9.3	10.38	18.3	5.1	0.4	75.70	7.15/2.17
			20	4.29	7.89	6.54	10.14			100.00	8.50/3.5

Table XIII. Turning Data for Forty Knot Turns with Waves
(Continued)

SIMULATION U	a	λ	δ rud	PITCH ANGLE θ MAX	PITCH ANGLE Δθ MAX	ROLL ANGLE ø MAX	ROLL ANGLE Δø	YAW MAXIMA	YAW MINIMA	YAW FINAL	YAW AVERAGE SIDE SLIP
40	2.0	36	5	1.19	1.89	4.36	7.72	1.6	.1	23.39	2.2
			15	1.74	2.1	4.34	7.71	5.2	2.5	72.10	5.3
			20	1.48	2.46	4.75	8.73	6.7	3.5	94.23	6.5

* Simulation run aborted due to negative fan horsepower.

Table XIV. Maxima/Minima Summary for Turns with Waves

	MAXIMA					MINIMA				
	Value (deg)	Simulation U (ft/sec)	a (ft)	λ (ft)	δ_{rud} (deg)	Value (deg)	Simulation U (ft/sec)	a (ft)	λ (ft)	δ_{rud} (deg)
ROLL	4.84	40.0	0.5	72.0	5.0	1.68	40.0	0.5	36.0	5.0
ROLL	9.35	40.0	0.5	72.0	5.0	0.90	100.0	0.5	36.0	5.0
PITCH	3.09	40.0	1.0	216.0	5.0	0.66	50.0	0.5	36.0	5.0
PITCH	4.51	50.0	1.0	216.0	15.0	0.27	100.0	0.5	36.0	15.0

straight runs with waves, runs were aborted when plenum gauge pressure surpassed 120 psf. Runs with wavelengths of 36 feet provided a slight decrease in gauge pressure. Speed drop-off was also noted with increasing time, speed, wave amplitudes and decreasing wavelengths with the exception of 36 foot wavelengths where final speed values increased.

IV. DISCUSSION/EVALUATION OF DATA AND PROCEDURE

The original plan of attack for obtaining turning data was both broad and sound considering the fact that no information other than Reference 1, the user's manual, was available for simulation information. The data base was established by determining relationships for straight runs with simple waves, and by determining craft reaction to calm water condition turns. The procedural part of the original plan was to utilize a wide set of data points by, varying speeds from 40 knots to 105 knots, varying rudder angles from five degrees to twenty degrees, varying wavelengths from one half of a craft length to ten craft lengths, varying wave amplitudes from 0.5 to five feet, and varying wave directions from 180, 90, and 000 degrees relative. The sheer magnitude of possible data accumulation demanded that data points be minimized and chosen so as to provide a wide spectrum of relevant data. Thus, after initial conditions had been found for speeds in five knot increments from 40 knots to 105 knots, the field was cut to only seven speeds for the straight runs with waves. Prior to proceeding to the turns with waves, it was decided to limit initial wave direction to port beam waves. The beam wave data from the flat turns were further subdivided and only 40, 60, and 100 knot information was extracted. Finally, of 84 possible simulation runs for each of the seven speeds for the turns with waves simulation, 28 of these were deleted and only a

total of 24 runs, 5, 15, and 20 degree rudder turns, were recorded for the broad analysis. In the final analysis, only the 40 knot turns were presented in this study.

A. PHASE I DATA BASE

1. Straight Runs

The straight simulation runs with no waves set the initial conditions for all succeeding runs. Although steady state conditions were not determined for the higher speeds, U = 95, 100, and 105 knots, it was decided to accept the average values as steady state conditions.

2. Straight Runs with Waves

The first simulations with waves utilized long wavelengths and small wave amplitudes with the intent of extracting information due to nominal perturbations of the wave effects at what approximated a wave of infinite length relative to the craft's dimensions. Unfortunately, the first wavelength used, λ = 720 feet, yielded more reaction than had been expected. Rather than increasing wavelength to approach the originally desired relative infinite wavelength, it was decided to halve the wavelength to five craft lengths or λ = 360 feet. The final decision to use wavelengths of λ = 216, 144, 72, and 36 feet was based on two main ideas. Firstly, there had to be a choice of wavelengths that would provide relevant data. Secondly, actual seas encountered by such a craft would not usually be of the extreme wavelengths as encountered in open seas by larger vessels.

In the procedure section above, it was noted that wave encounter frequency played an important role in the ship's stability characteristics. Roll, pitch, and yaw all oscillated with some relationship to this wave encounter frequency. The relatively gross one-half second print interval used to determine the values for the beam wave simulations showed only a general relationship and negligible phase information. Figure 17 shows wave amplitude for a straight 40 knot run with $\lambda = 216$ and $a = 0.5$ feet. When wave amplitude was compared with Figures 18 and 19, plots of roll and pitch, it was readily seen that roll and pitch were definitely wave encounter frequency related with only a slight delay time. Interestingly, the roll and pitch producing moment plots, Figures 20 and 21, showed no such clarity for frequency or phase relationships due to the irregular formation of the moment curves. However, when the roll and pitch curves were compared to their respective moment curves, it was noted that they were approximately 180 degrees or about one-half of a wave encounter period out of phase.

The loss of speed noted in the wave procedure was due to the increased drag caused by the wave. Figure 22 shows wave drag in the x-direction with varying rudder applications under calm water conditions. The important part of Figure 22 for this example is that it illustrated an initial wave force which was constant until the rudder was put in motion at the two second time of simulation.

It is this initial wave drag which when coupled with the additional hydrostatic drag forces caused loss of speed. As velocity decreased more wave drag was experienced, see reference [2], and speed was further decreased. The end result was that eventually a steady state would be reached whereby the initial thrust as set into the simulation for the desired initial speed would eventually equal the total drag forces thereby reaching a steady state speed. Times for this steady state solution were considerably longer than the 25 second simulation runs used in this report.

For the bow and stern waves the roughest perturbations experienced by the craft were simulations with λ = 144 feet. Beam waves similarly provided maximum distrubances at λ = 72 feet. The cause of this had to be attributed to the craft's dimensions. For longer wave lengths the craft experienced a rise and fall with the wave encounter frequency. However, for wavelengths of equal size to or smaller than the dimension in question, the 75 foot length for the bow and stern waves and the 36 foot width for beam waves, angular displacement excursions were greatly reduced due to the rapidly changing wave forces. The fact that these angular excursions were less was not in itself a fortuitous occurrance. As noted in Table IV, the only aborted runs were at the lower, 36 foot, wavelengths for the beam waves. Additionally, all of the aborted runs for bow and stern waves, not shown, occurred at wavelengths of 72 feet or less. The reason for these aborted runs was the excessive

angular accelerations experienced by the craft due to increased wave encounter frequencies and increased wave amplitudes.

B. PHASE II TURNING DATA

1. Calm Condition Turns

Most of the data collected did not indicate any unexpected results. Roll, pitch, and yaw rate all experienced some type of decaying oscillation commencing with time t = 2 seconds, the beginning of rudder motion. This rudder motion was considered to be a ramp input until it reached its final desired value and remained a constant at that value throughout the simulation. With the cessation of rudder motion, force values due to rudder change also began an oscillatory decay. Roll characteristics will be discussed in greater detail below, but for the most part roll attempted to reach a steady state heeling attitude to port. Pitch final values, as noted in Table IX and illustrated in Figures 2, 5, and 8, for 5, 15, and 20 degree turns with speeds of 40, 85, 100 knots, oscillated about values less than the initial condition values. Figures 2, 5, and 8 indicate that the more rudder applied the greater the average pitch angle. Yaw as opposed to roll and pitch seemed to be fairly steady when viewing Figures 3, 6, and 9. However, Figure 10 shows that a 40 knot simulation did experience oscillations in yaw rate producing more oscillation with the smaller rudder angles.

2. The Roll Phenomenom of the 40 Knot Turns

As noted in the procedure, positive peak overshoot, roll to starboard, was much greater for five degree rudder than for either 15 or 20 degree rudders; Figure 1. The whole problem was eventually resolved by calculating the breakdown of the roll producing or the components of the moments about the x-axis. When data such as found in Tables XL and XII were properly correlated on a time basis, it was seen that values of the components were exactly equal until immediately after the rudder stopped its swing. Thus, at times greater than three seconds for the five degree turn, and times greater than five seconds for the 15 degree turn, a different problem was generated than for the 15 degree and 20 degree turns respectively. In that the clockwise motion of the rudder produced greater negative roll moments with increasing rudder at print time 3.5 seconds, the negative moment component due to the rudder was much greater for the 15 and 20 degree rudders than for the five degree rudder. Similarly, at print time 5.5 seconds, the negative moment for the 20 degree rudder was significantly larger than the moment for the 15 degree rudder. As the craft begins to turn the dynamics are such that the summation of forces, and for that matter the direction of motion, is not always directed along the craft's longitudinal axis. In fact, for a turning maneuver with constant rudder a new line of force is generated. This direction of motion relative to the craft's heading is known as side slip angle.

In the simulation program, side slip angle is simply determined by

$$\text{Side Slip Angle} = \frac{V}{U} \tag{23}$$

in radians. The initial motion of the rudder provides this change in force direction. At this point, from Table XIII, it was noted that with increasing sideslip angle the positive component of roll moment due to the sidewalls increased until the moment component peaked within one-half of a second after the rudder motion had stopped. Average sideslip angles were 2.1, 5.8, and 7.2 degrees for 5, 15, and 20 degree rudder turns respectively. Obviously, the increasing side slip angle produced increased moments with higher rudders, however; as noted above, these values did not peak until after cessation of rudder motion. Thus, at time 3.5 seconds the slightly large positive moment due to the sidewalls coupled with the notably smaller negative moments for the rudder produced a much more positive roll reaction, roll to starboard, than in the cases of the 15 and 20 degree turns.

3. Turns with Simple Waves

The results of the first runs of turns with waves showed that the best conditions generated by the beam wave case soon deteriorated as the craft's heading turned toward the wave front. Due to the one-half second print interval decided upon for all the runs, frequency and phase analysis

for turning characteristics were not carried out. Figure 23 plots the wave amplitude for a 40 knot 15 degree rudder run with λ = 216 ft and a = 0.5 ft. Notice in particular how encounter frequency had increased near the end of the 25 second run. Figures 24 through 26 show the same 40 knot turning run compared to a 40 knot turn without waves in roll pitch and in displacement. Notice that the frequencies of the decaying oscillations matched to some degree the corresponding frequencies for no waves with only slight time delay. Notice also that in Figure 26, the turning path for the wave case seems to have a much smaller radius than the radius for the no wave case. This is attributed to the z-axis moment added by the wave. Although cases were not run past the 25 second mark, it is assumed that the turning radius for the wave case would be correspondingly larger when the z-axis contributed by the wave acts against the direction of turn when completing a 360 degree turn.

As with straight run waves, turning runs with waves seemed very dependent on wavelength. Slower runs with long wavelengths yielded maximum perturbations in roll, pitch, and roll rate. For turns with waves, the drop off point for some parameter excursions, and the minimum for others was for wavelengths of λ = 36 ft. This seems reasonable since as in the above straight run simulations with beam waves, the beam dimension of 36 ft produced the same results when considering wavelengths.

V. CONCLUSIONS

A. TURNING CHARACTERISTICS

The study of any craft's turning characteristics in the final analysis must be based upon actual turning data generated by a prototype craft. For the purposes of this study, correlating data could have generated more definite conclusions as to the validity of turning characteristics presented above. However, since no such data has been made available only generalizations can be made as to the simulation capability of the Oceanic's program.

Basically, turning characteristics seemed to be compatible with previous knowledge and past experience. From a controls point of view, data tends to indicate that with this particular CAB/SES as modelled would be optimally utilized at higher speeds using larger rudder angles. Of course, the dangers of high speed maneuvering are obvious when considering increased and varying wave encounter frequencies. In that the craft was designed for high speed operations, control efforts should be directed at reducing both the acceleration and the maximum excursions of attitude parameters. As it is, the simulation showed only such small changes in these parameters that if the same perturbations were experienced by a displacement vessel, they would in general go unnoticed. However, since the CAB/SES is not a displacement vessel, these stability parameters are much more important.

Overall the simulation seems to be accurate when considering horizontal plane trajectories. As far as the above simulation runs were concerned, data obtained for vertical plane motion, heave in particular, leave room for some doubt. Original runs used the variable Runge-Kutta-Mersen numerical integration. As waves were introduced to the simulation runs, more computer time was required due to the small integration tolerances used and the numerous step size doubling and halving iterations. To prevent excessive computer time the tolerances in some cases were expanded thereby introducing small error. Most trajectories were relatively unchanged; however, the most sensitive output parameters dealt with plenum pressures and motions in the vertical plane. Final runs with turns and waves used a fixed step size of 0.005 seconds which was determined to be the average step size used by the Runge-Kutta-Mersen method. At the time of this writing, it seems that more accurate results could have been obtained with a 0.001 second step size while sacrificing four times as much computer time. For the purposes of this study, it is felt that the .005 second step size was sufficient.

B. RECOMMENDATIONS FOR FUTURE STUDY

The first and foremost objective is to determine if the loads and motions simulation is valid. When this study was initially undertaken it was with the idea of eventually comparing simulation data with actual test data. At the

time of this writing test data had not been made available. Once these data are compared more confidence will be gained in the loads and motions simulation thus enabling modifications in the simulation for larger craft. Additionally, steps should be taken to modify the simulation for the XR-3 to further develop understanding and confidence in the program. Once these steps have been taken the next obvious step is to model multi-thousand ton gross weight CAB/SES.

Once it has been proved that the basic program is adequate and that it can be modified, a very interesting field of study would be an optimal control system. Items to be condiered for these controls aside fron standard rudder and propulsion apparatus would be fan pressure control for the seals as well as the plenum, fins, and any other type of control surfaces that would enhance the stability control that would be required for high speed operations.

APPENDIX A

Figure 1. Forty Knot Turns:
Roll Angle Versus Time

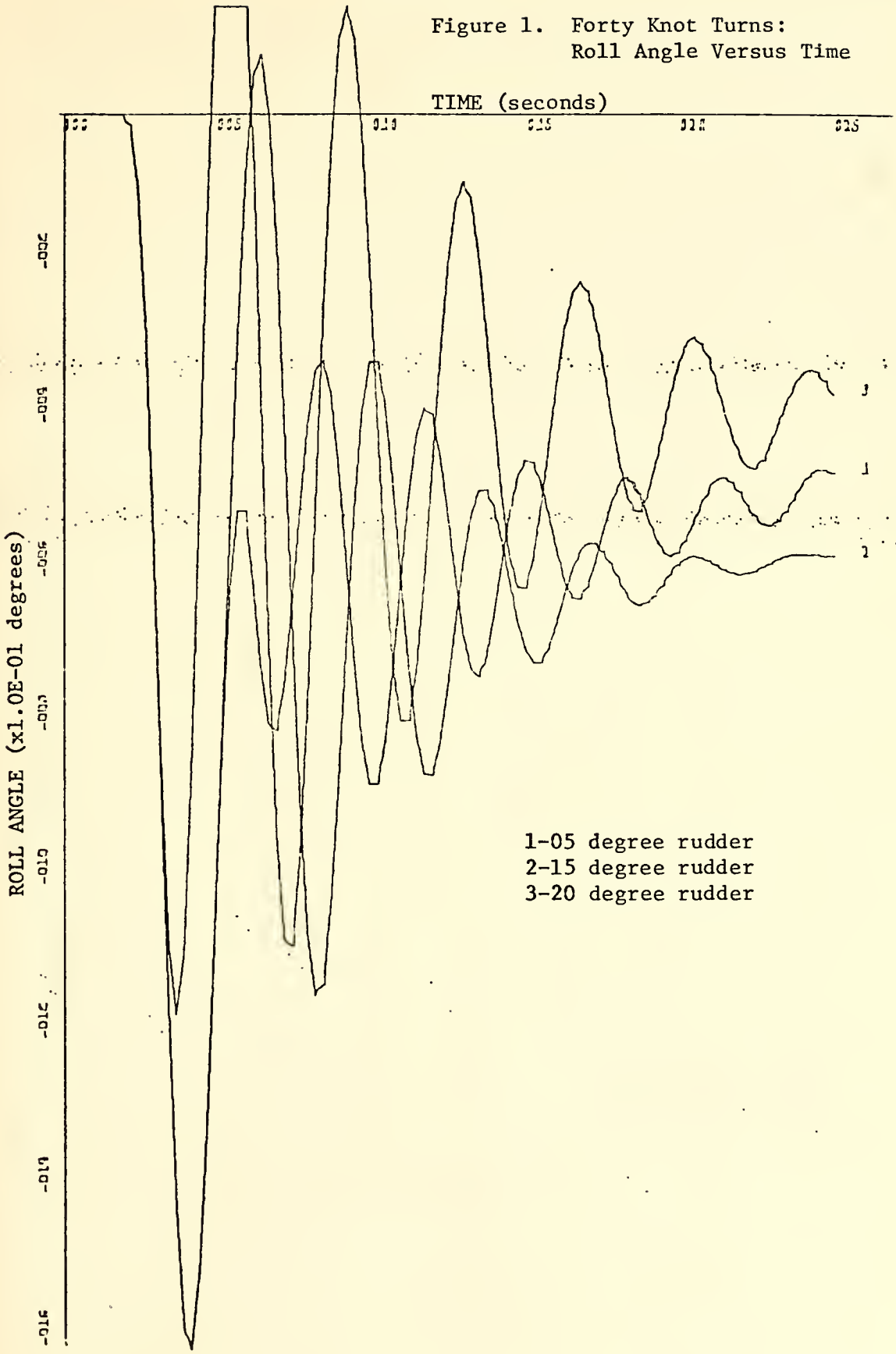


Figure 2. Forty Knot Turns: Pitch Angle Versus Time

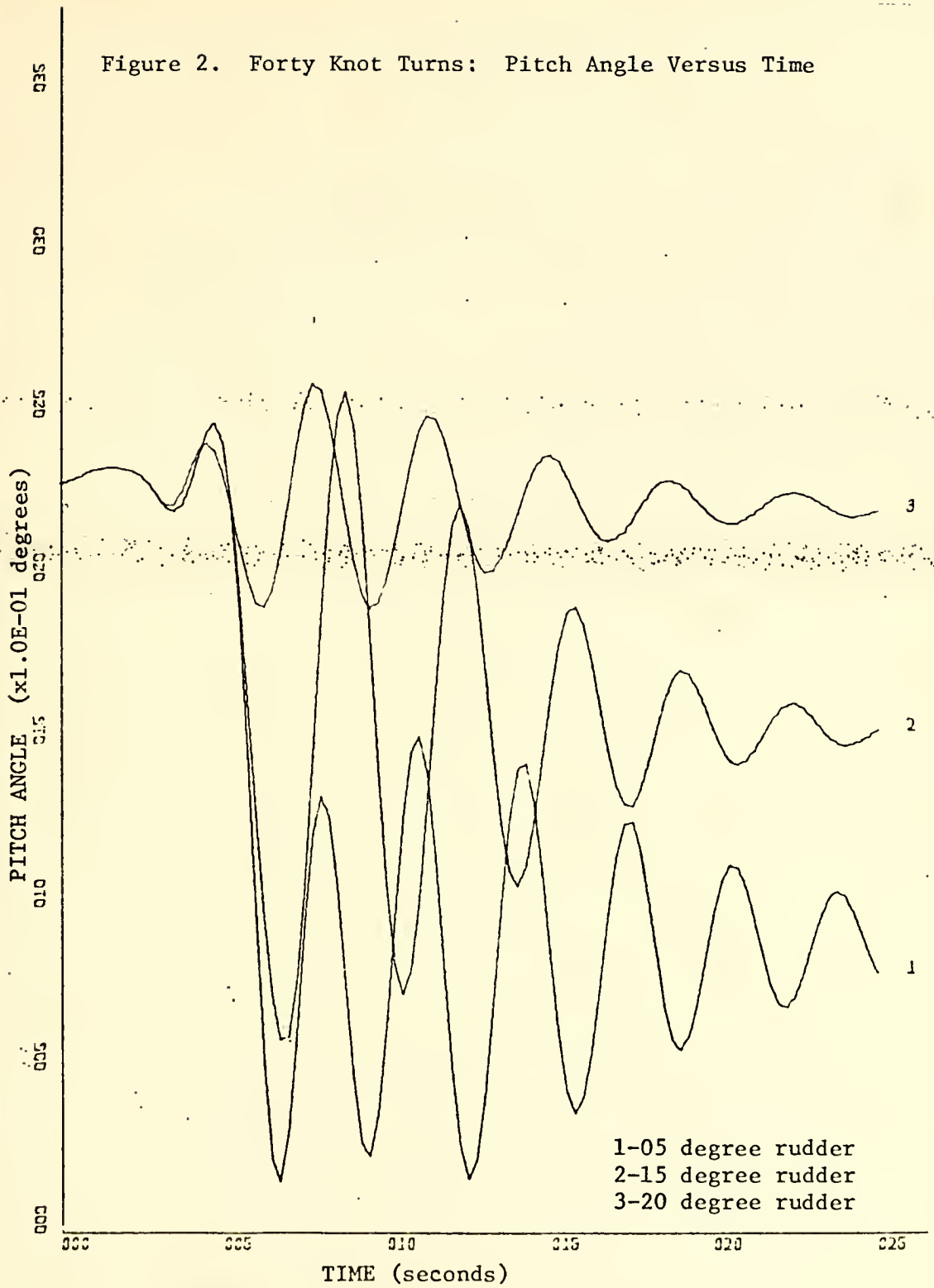


Figure 3. Forty Knot Turns:
Yaw Angle Versus Time

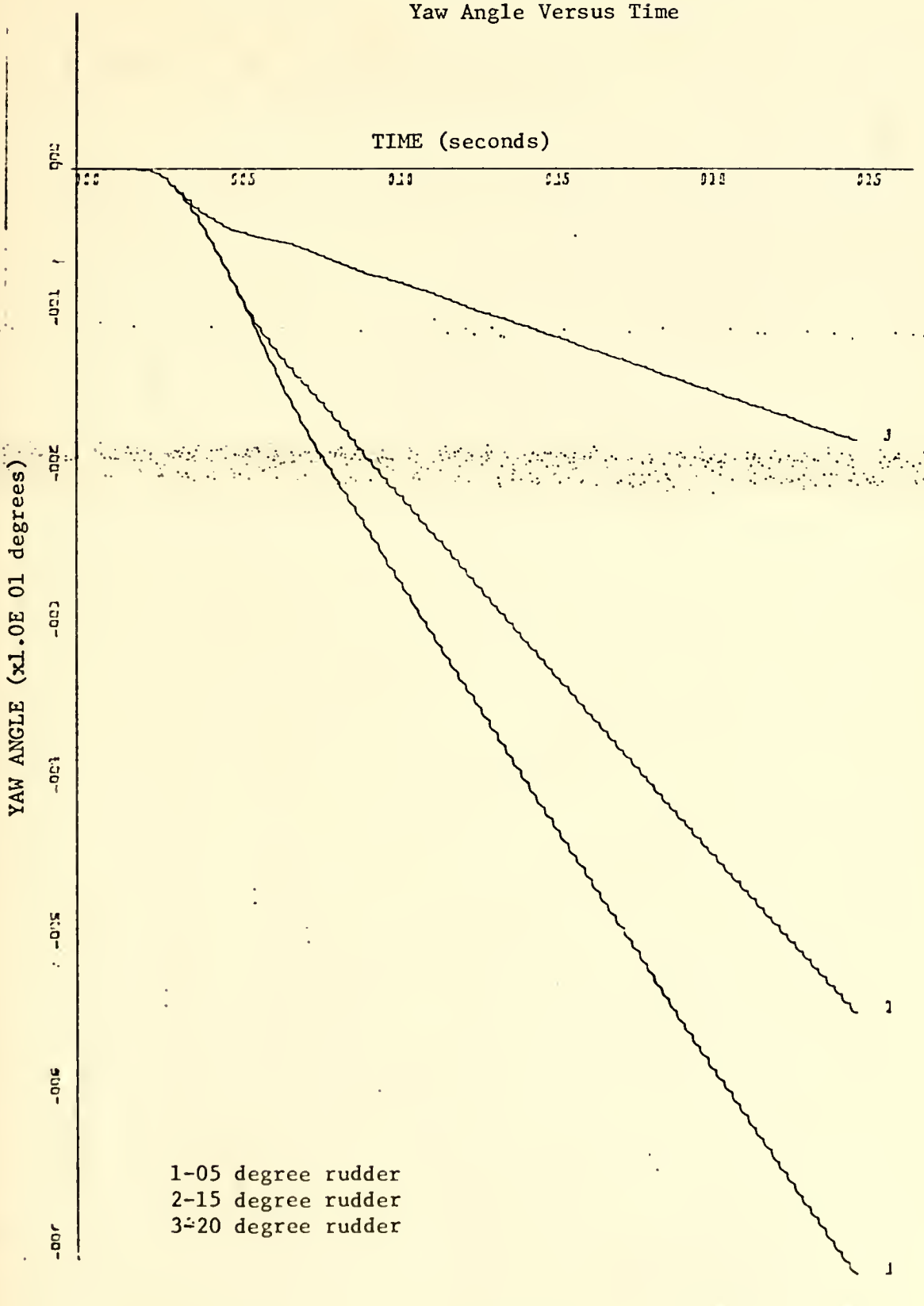


Figure 4. Eighty-five Knot Turns: Roll Angle Versus Time

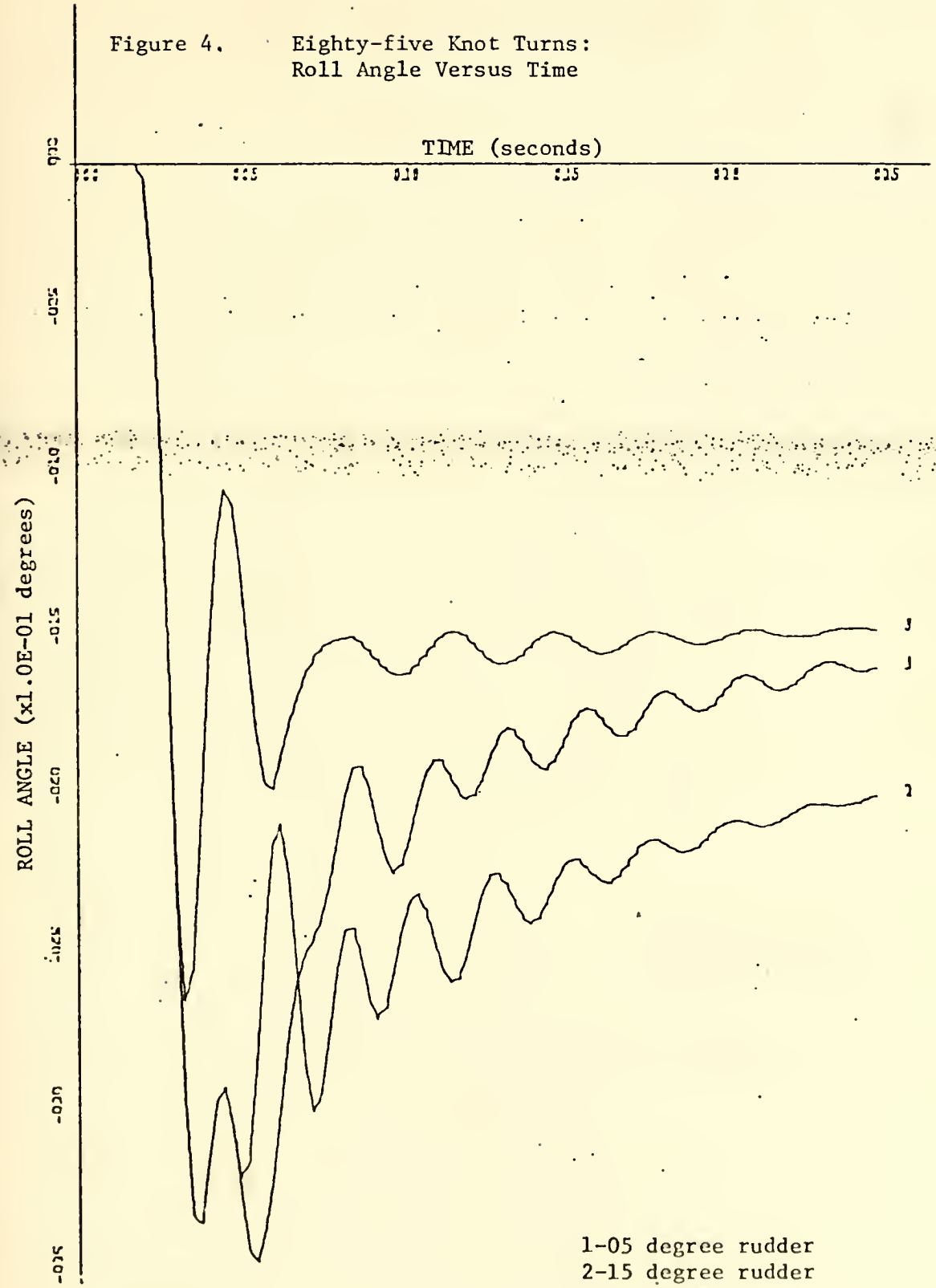


Figure 5. Eighty-five Knot Turns:
Pitch Angle Versus Time

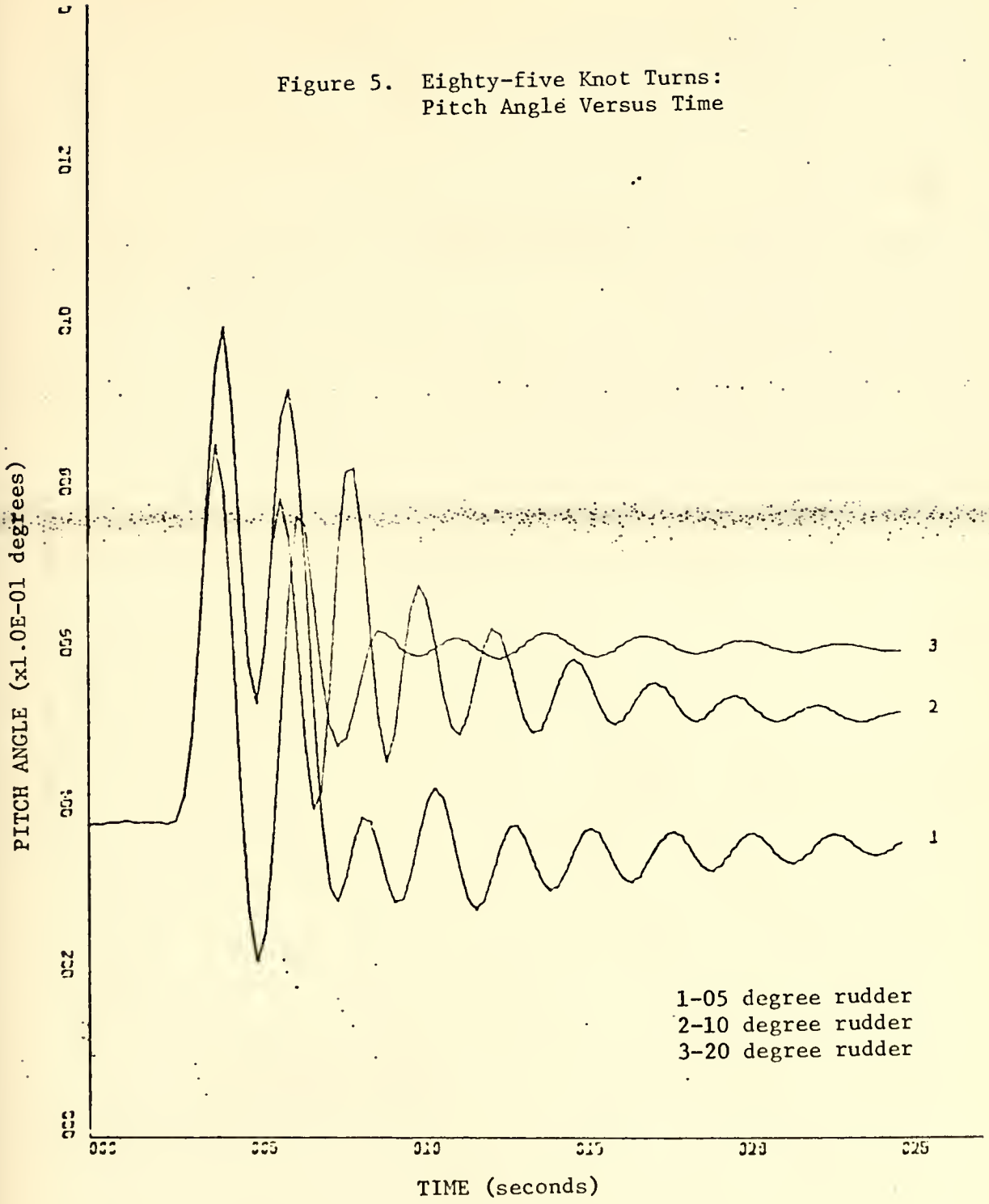


Figure 6. Eighty-five Knot Turns
Yaw Angle Versus Time

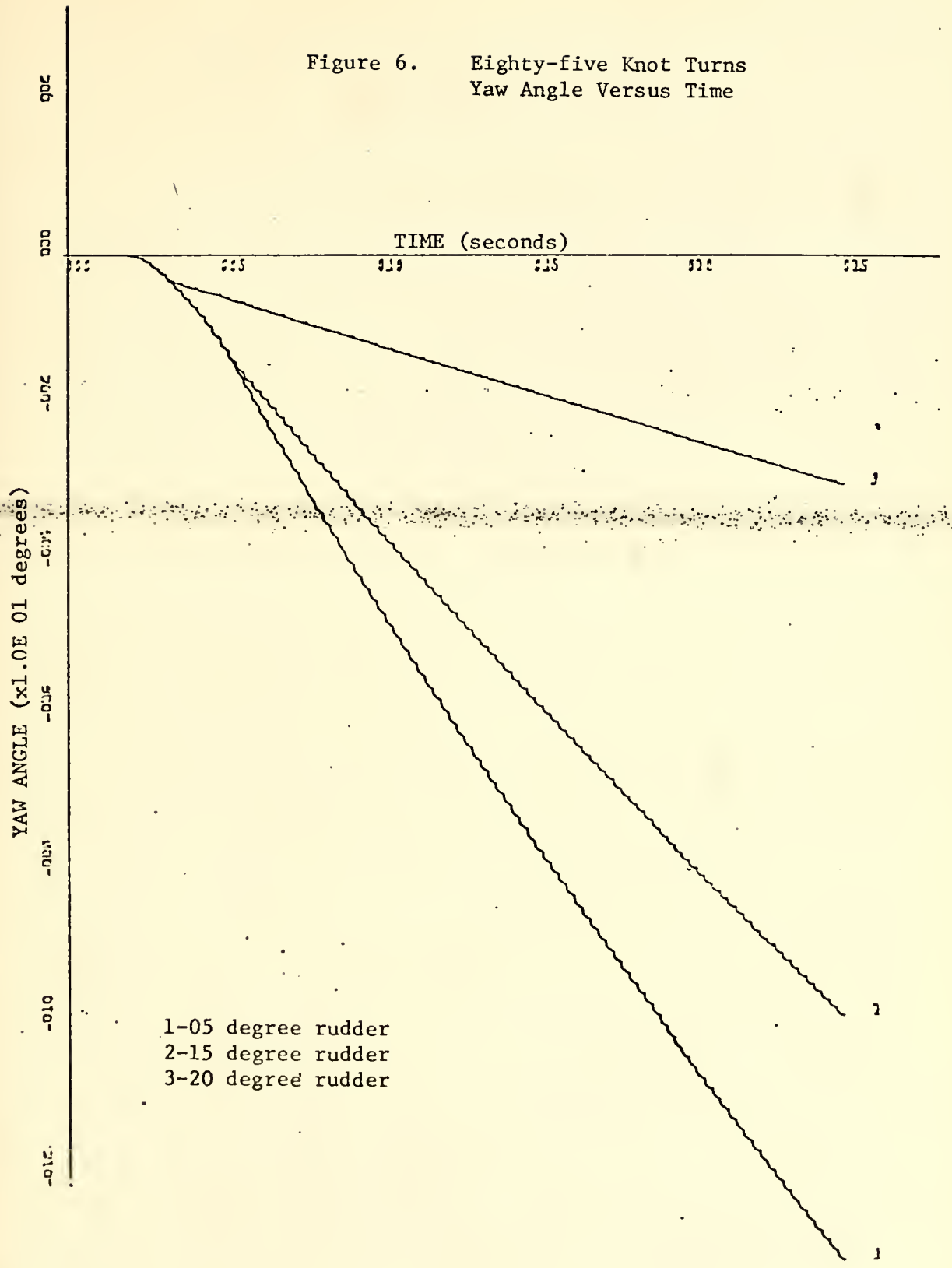


Figure 7. One Hundred Knot Turns:
Roll Angle Versus Time

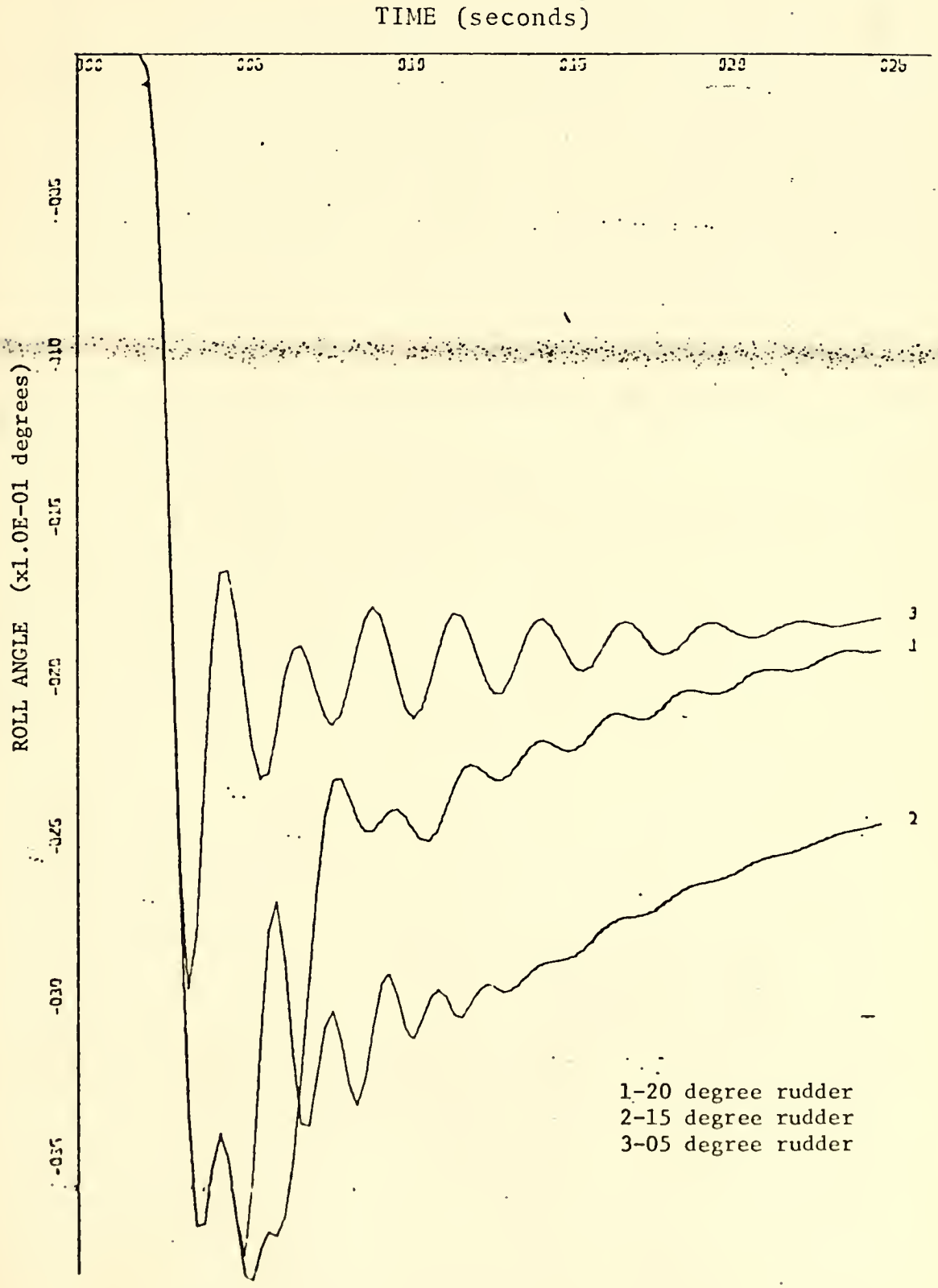


Figure 8. One Hundred Knot Turns:
Pitch Angle Versus Time

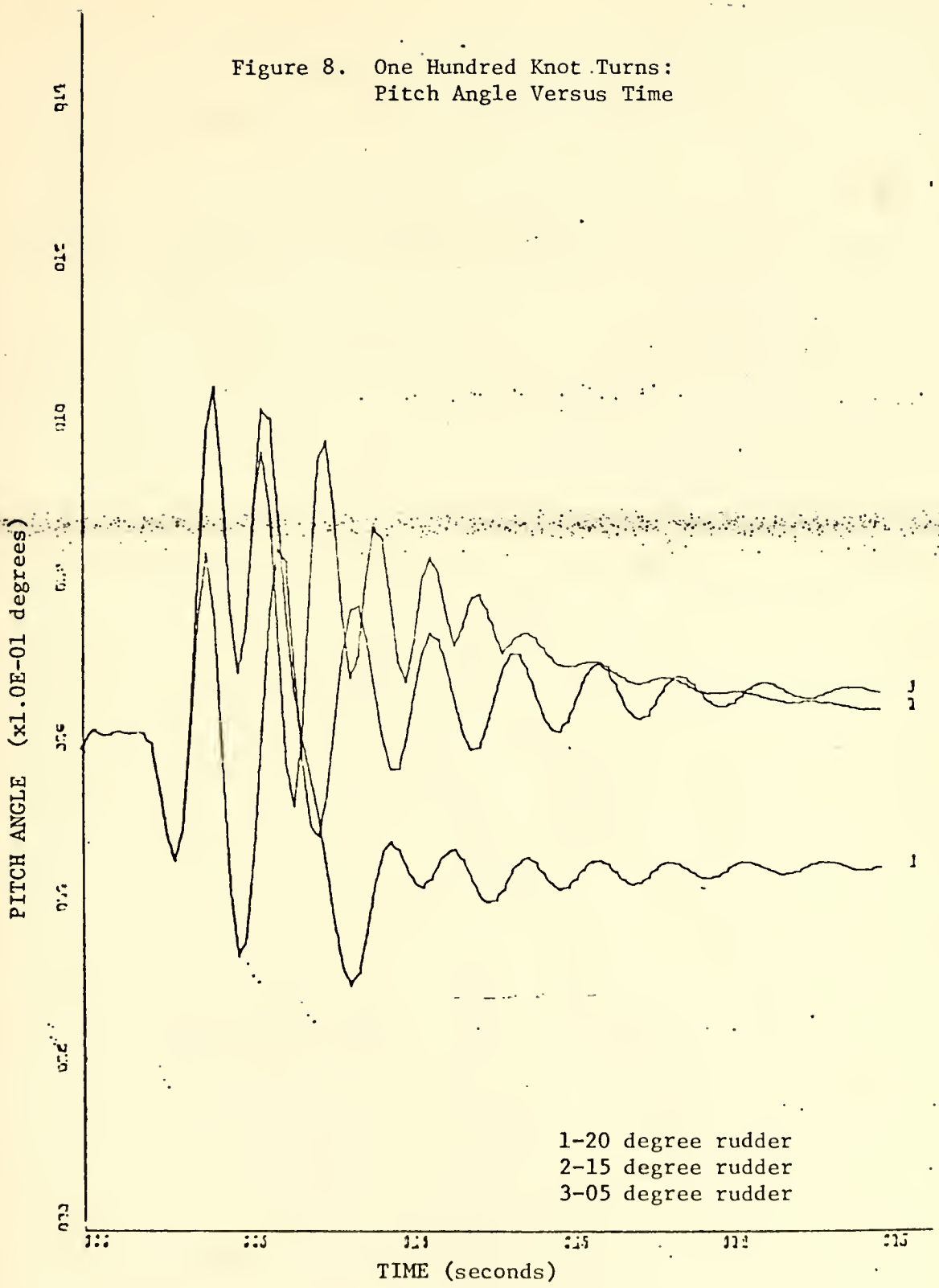


Figure 9. One Hundred Knot Turns
Yaw Angle Versus Time

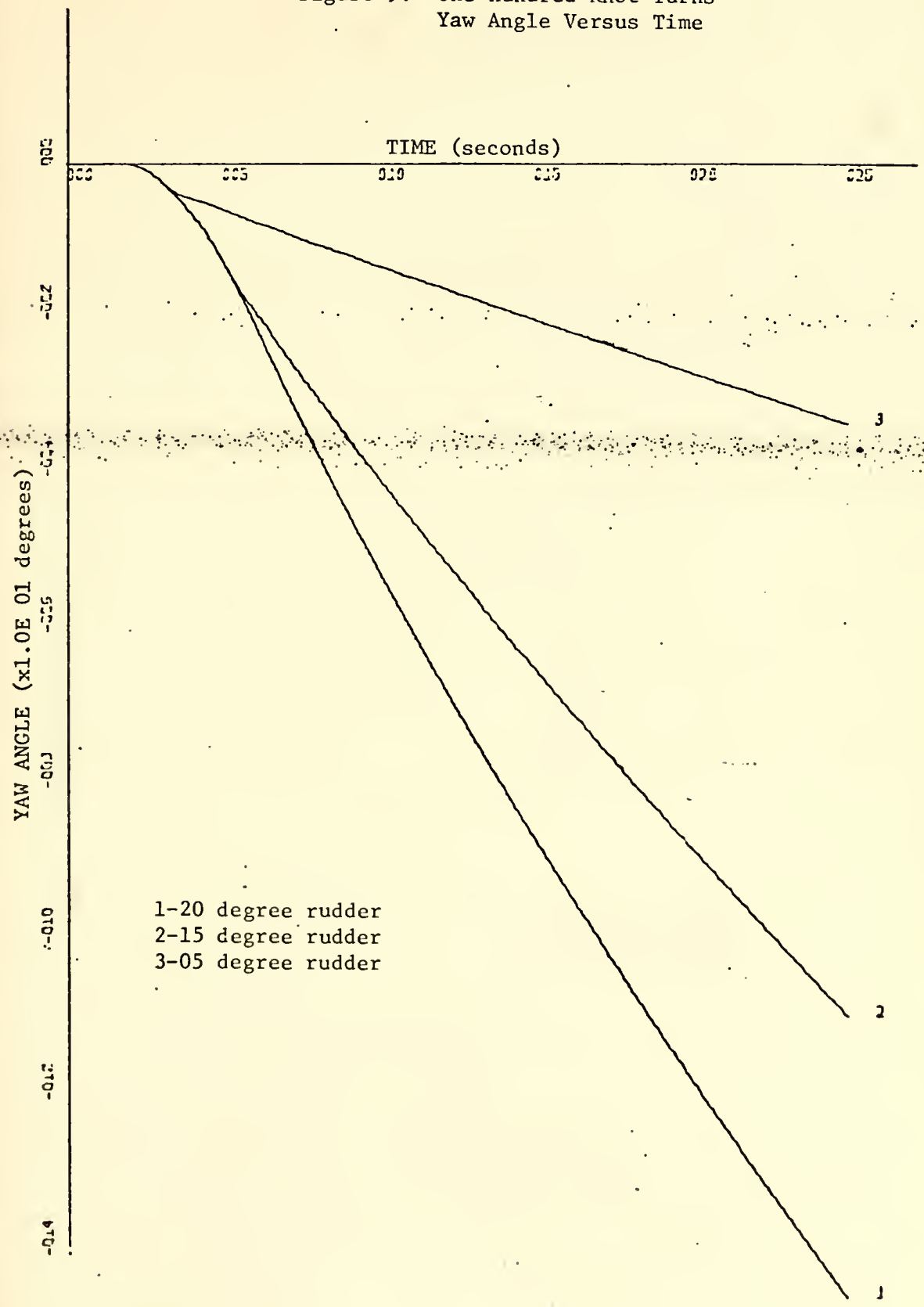


Figure 10. Forty Knot Turns:
Turn Rate Versus Time

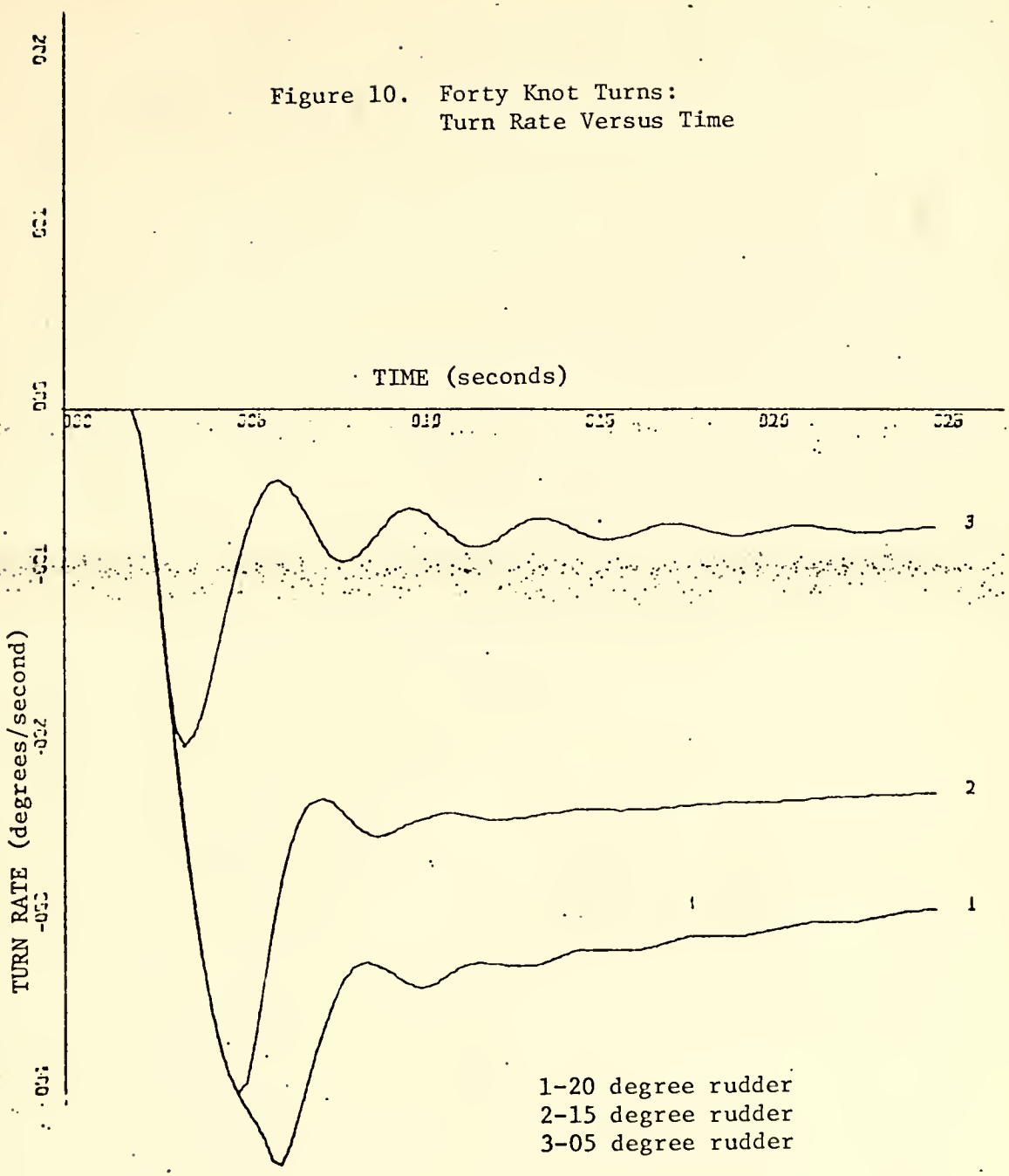


Figure 11. Forty Knot Turns:
Summation of Axial Forces Versus Time

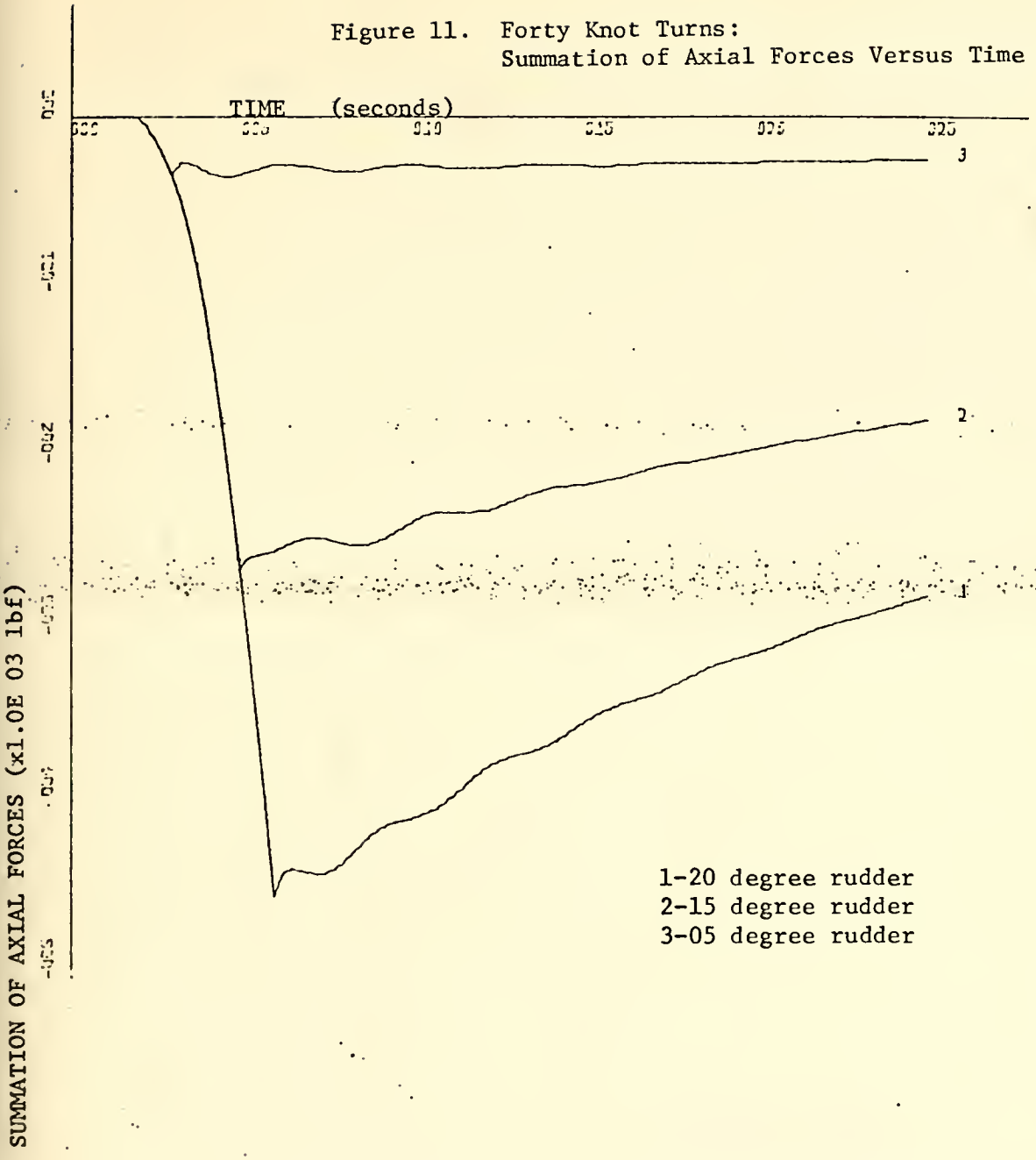


Figure 12. Forty Knot Turns:
Summation of Lateral Forces Versus Time

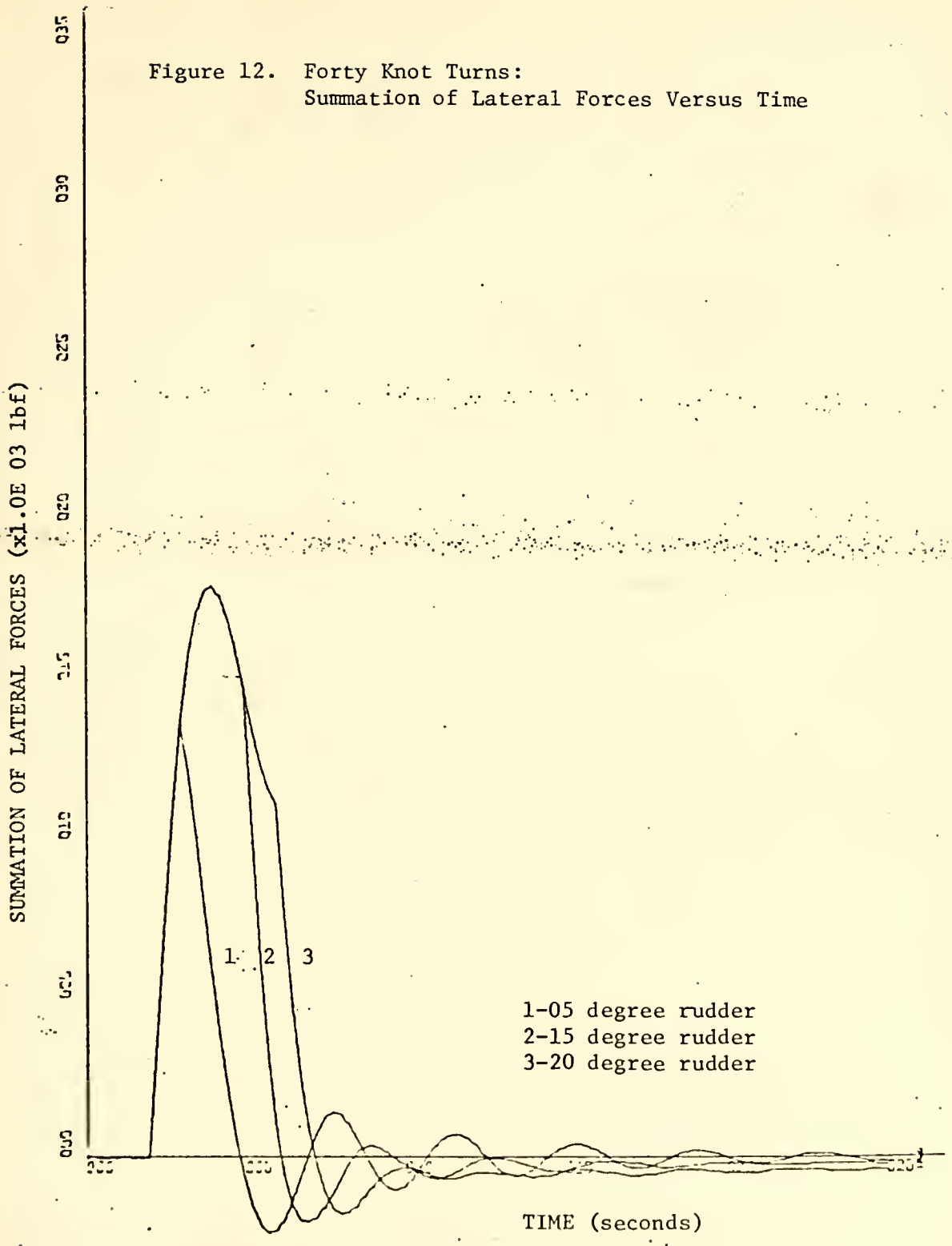


Figure 13. Forty Knot Turns:
Summation of Vertical Forces Versus Time

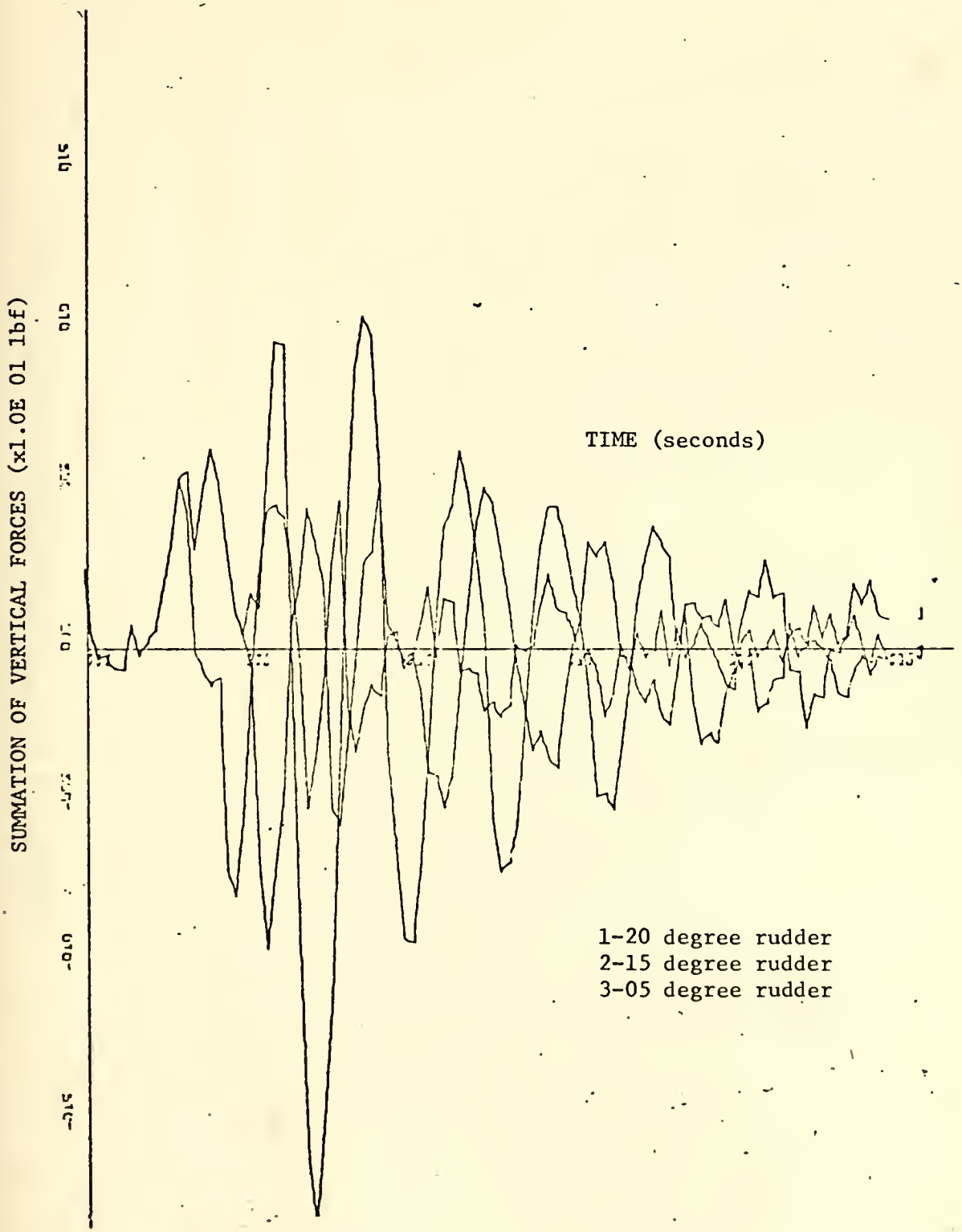


Figure 14. Forty Knot Turns:
Summation of Roll Producing Moments

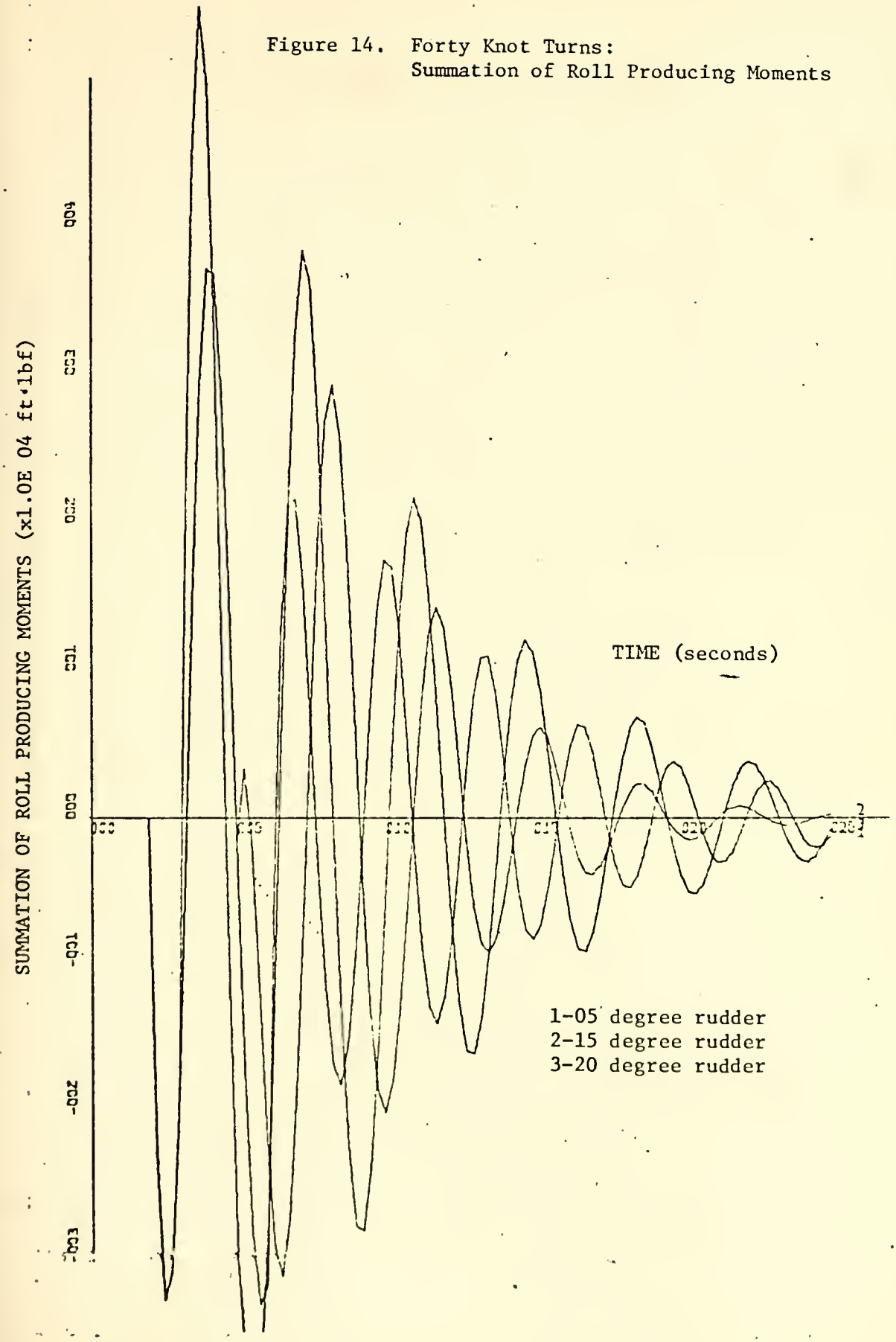


Figure 15. Forty Knot Turns:
Summation of Pitch Producing Moments

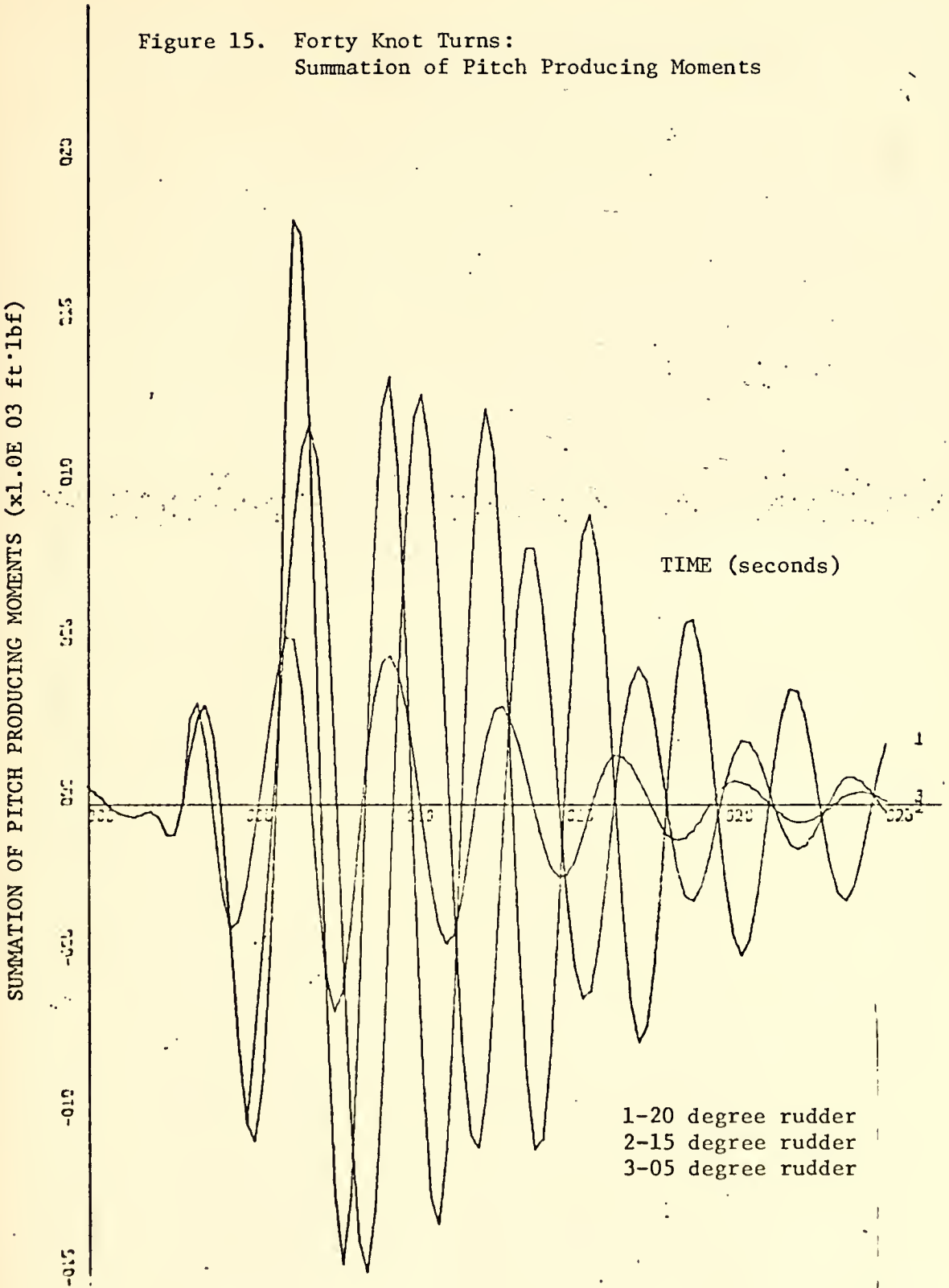
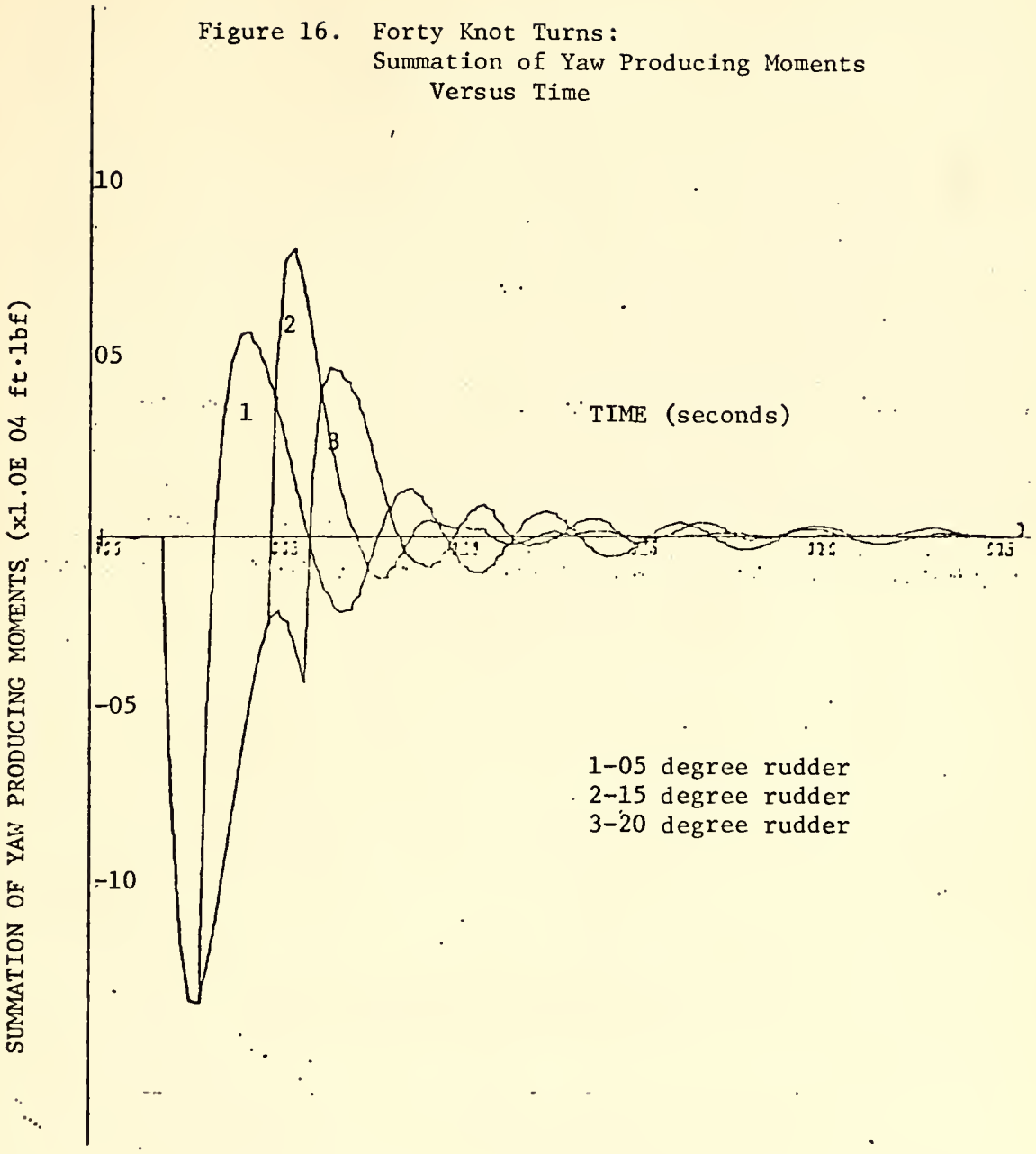


Figure 16. Forty Knot Turns:
Summation of Yaw Producing Moments
Versus Time



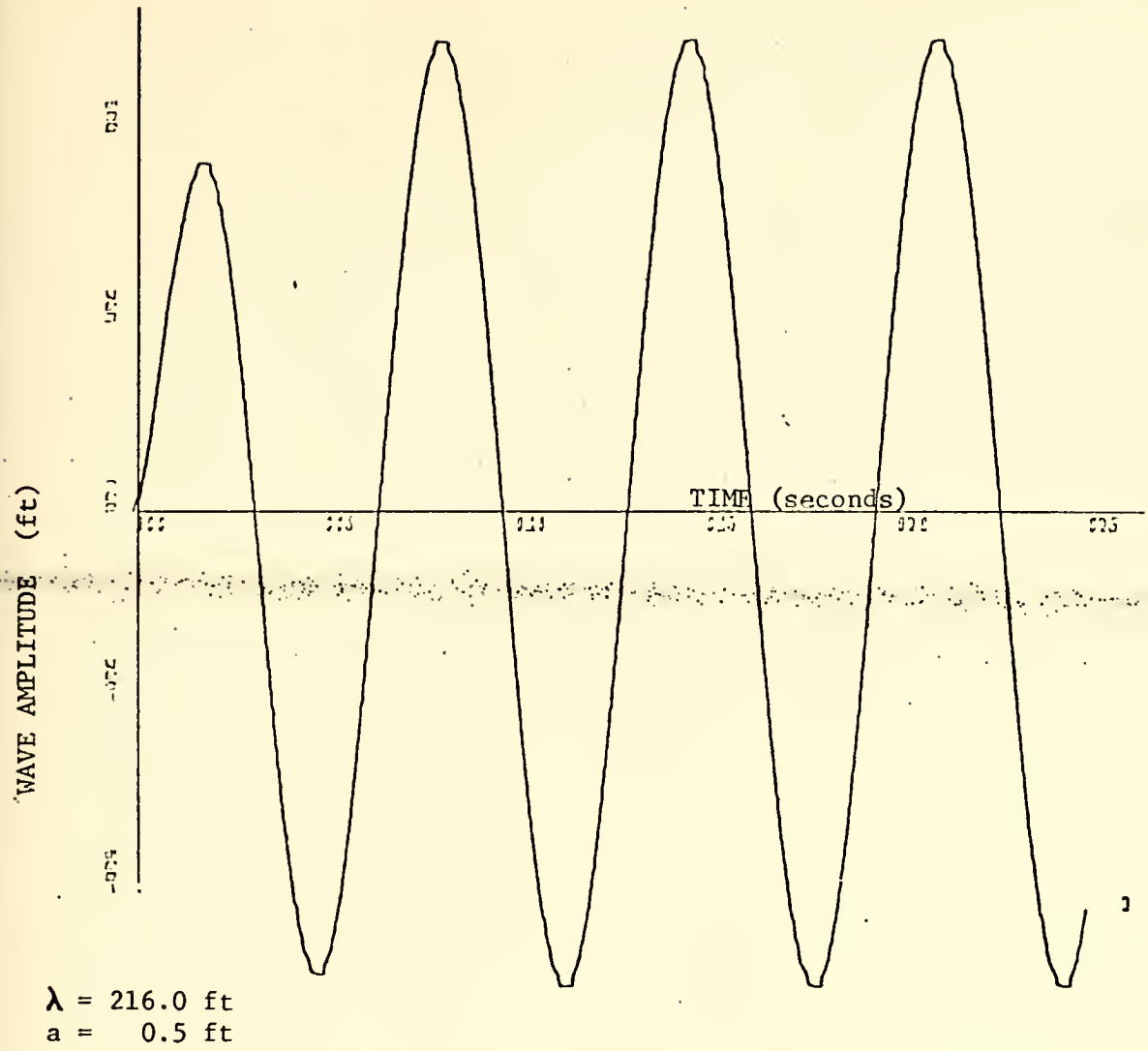
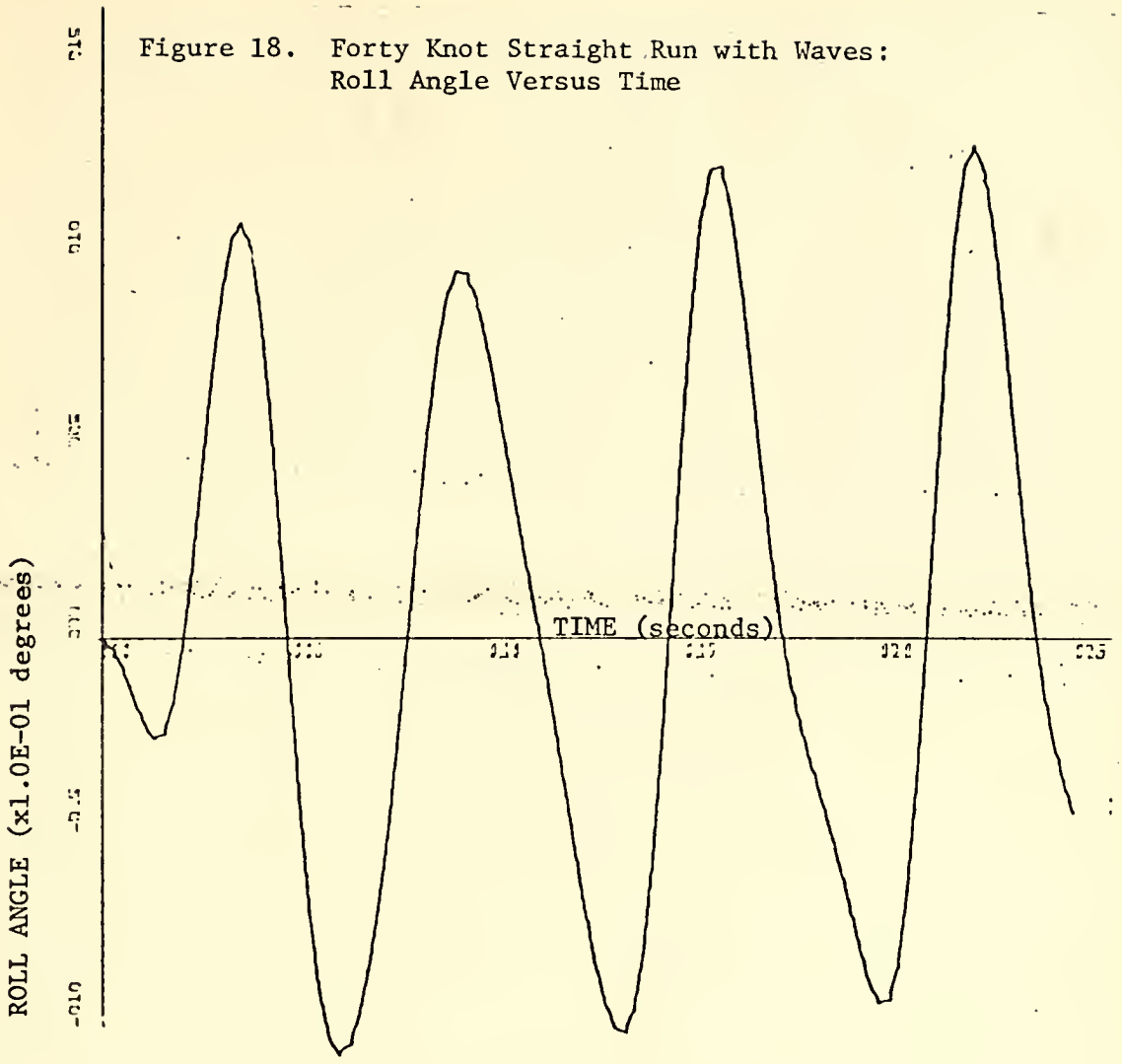


Figure 17. Forty Knot Straight Run with Waves: Wave Amplitude Versus Time

Figure 18. Forty Knot Straight Run with Waves: Roll Angle Versus Time



λ = 216 ft
α = 0.5 ft

Figure 19. Forty Knot Straight Run with Waves:
Pitch Angle Versus Time

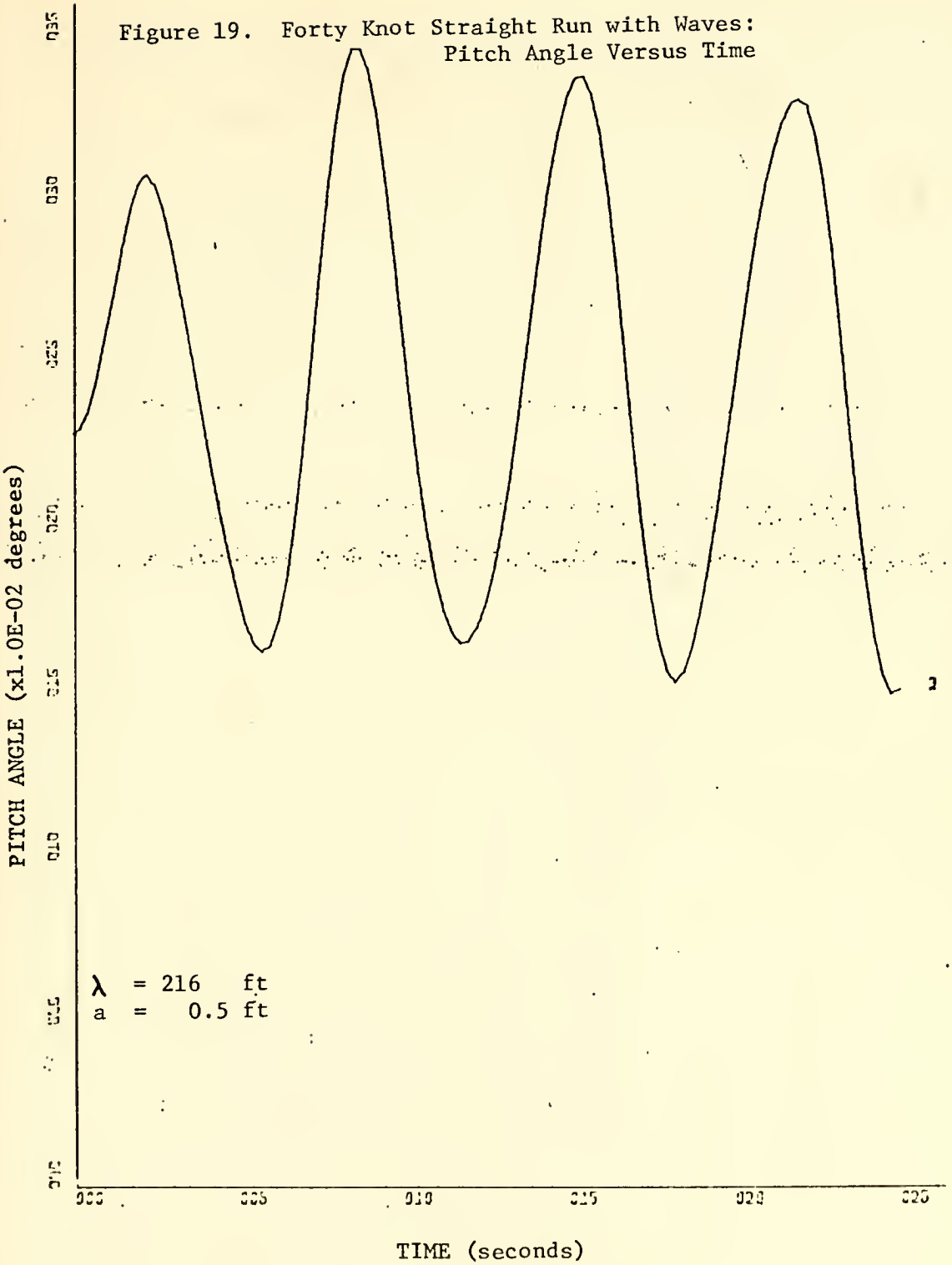


Figure 20. Forty Knot Straight Run with Waves: Summation of Roll Producing Moments

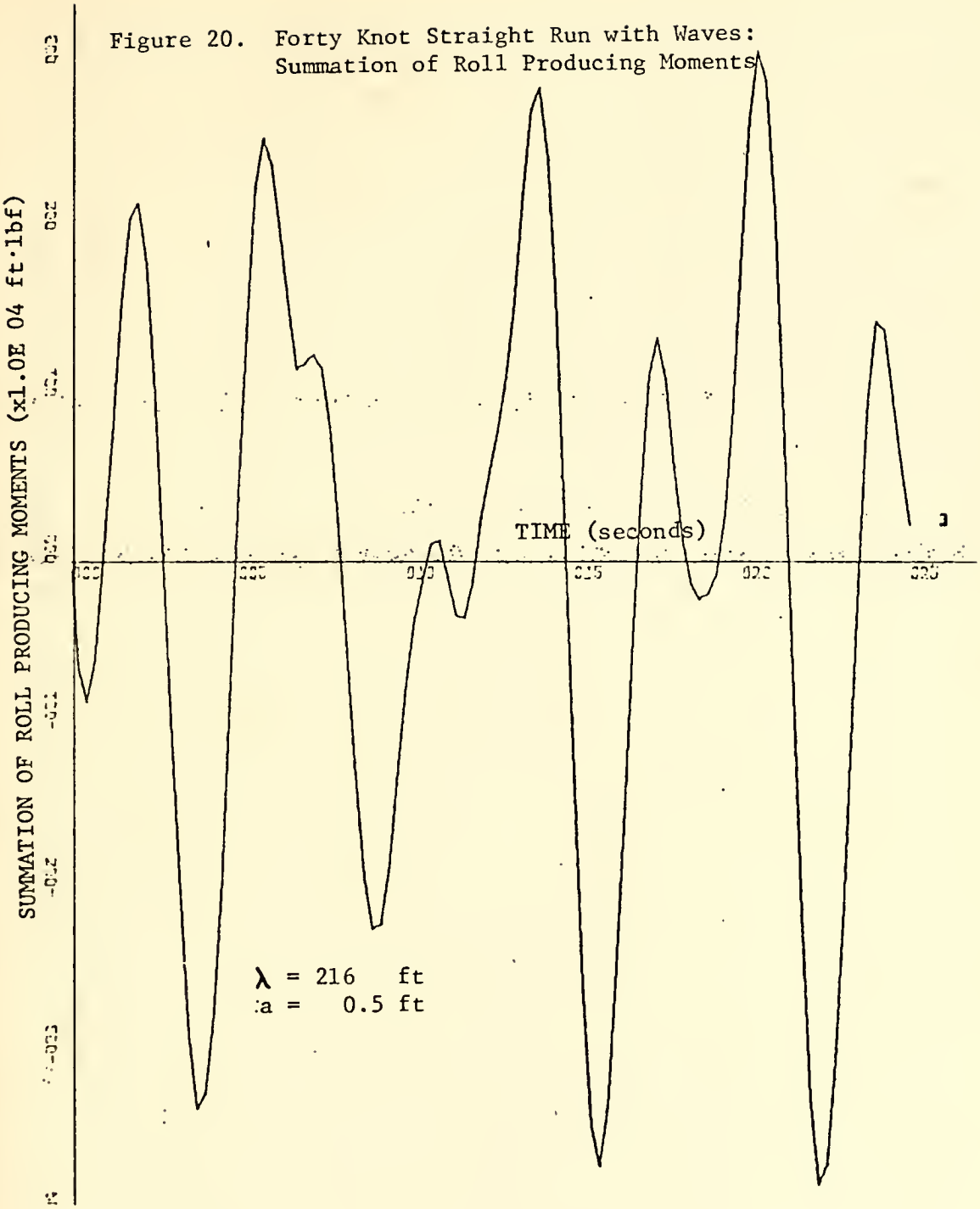


Figure 21. Forty Knot Straight Run with Waves: Summation of Pitch Producing Moments

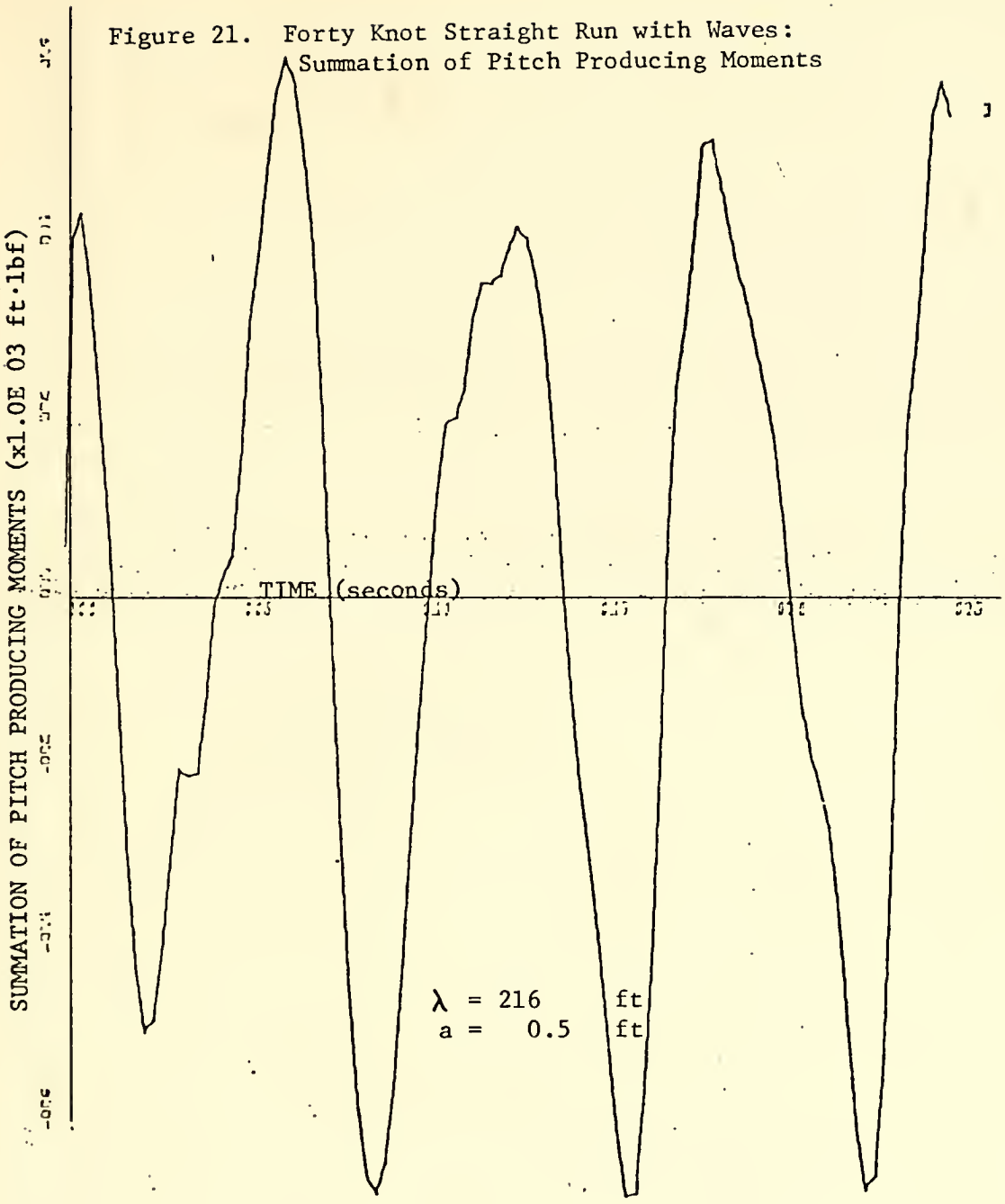


Figure 22. Forty Knot Turns: Wave Force X-direction Versus Time

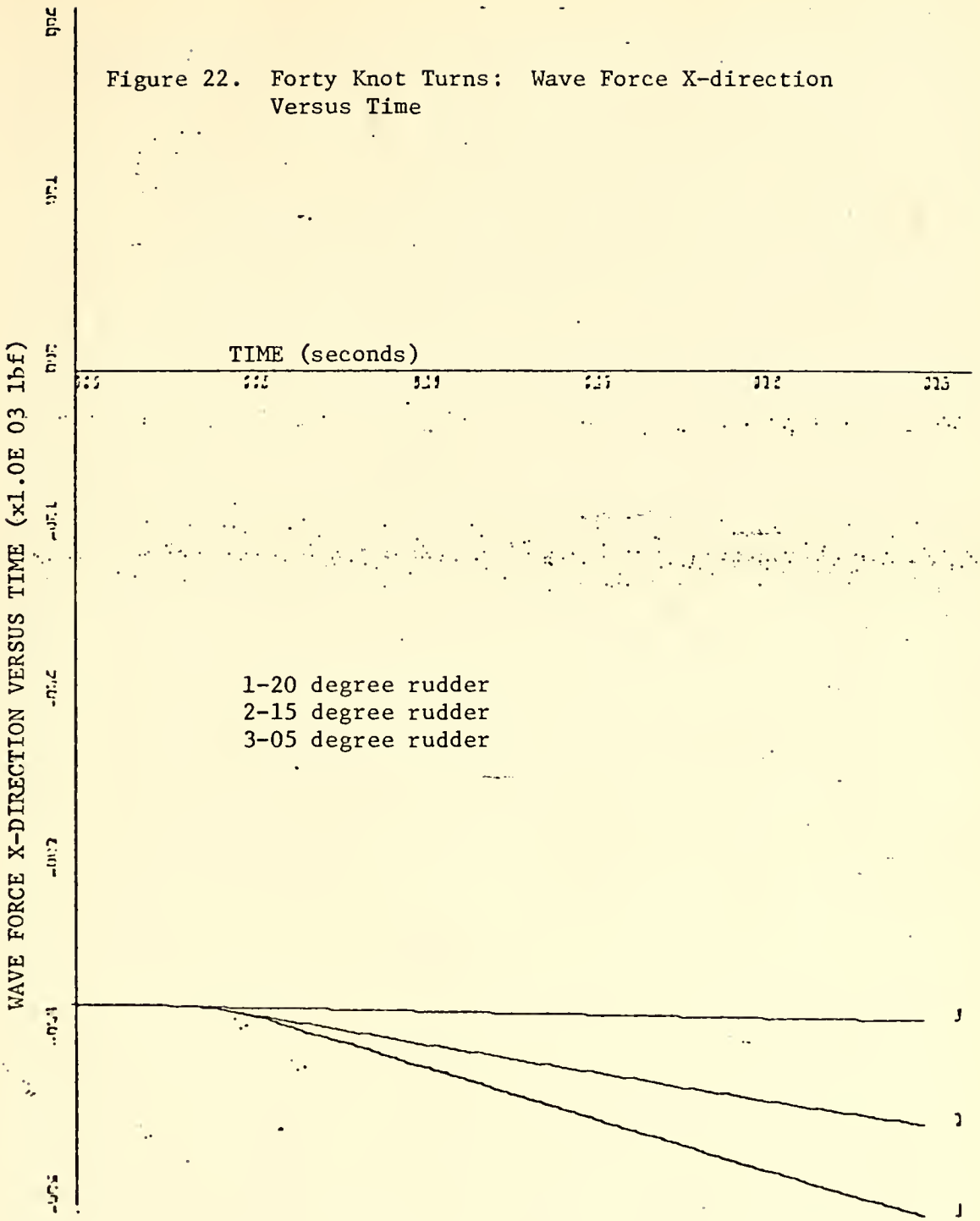
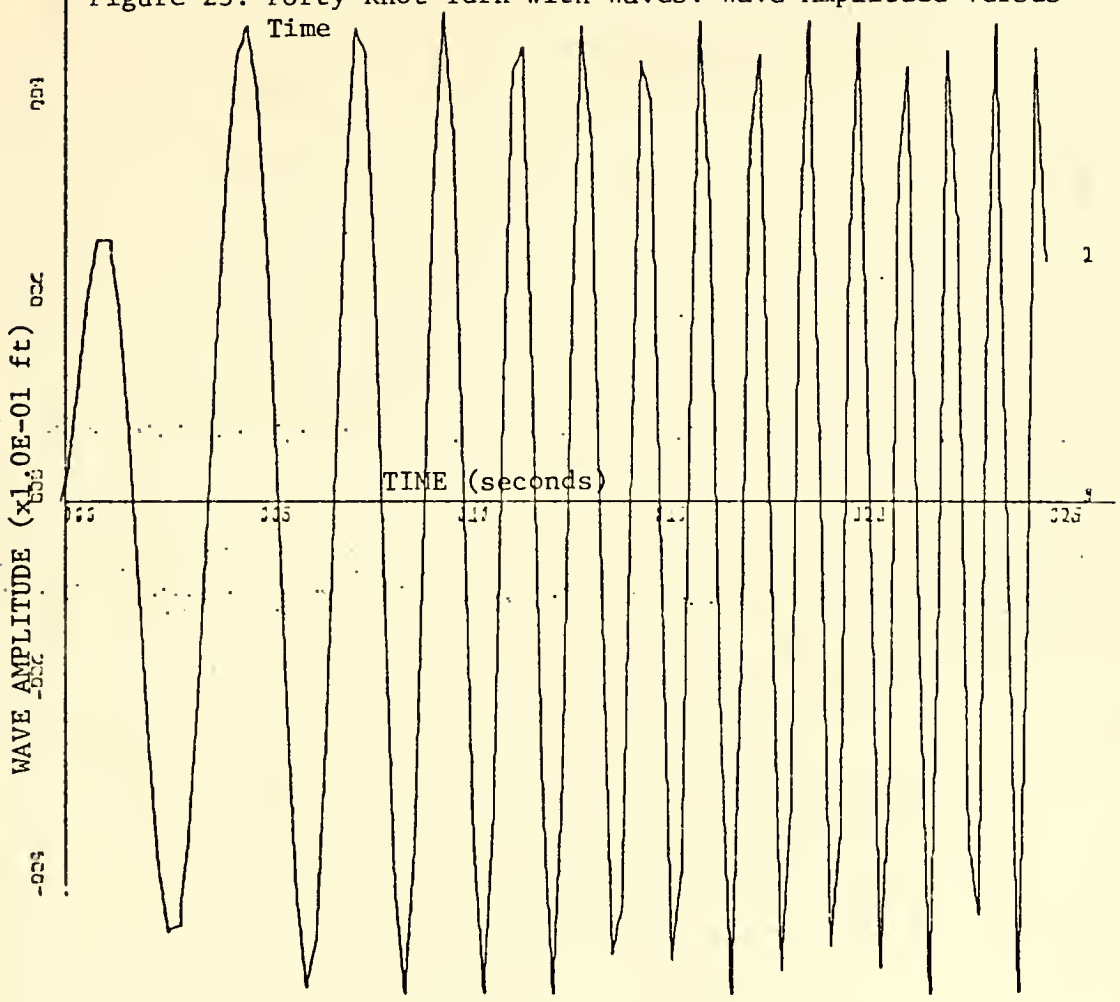


Figure 23. Forty Knot Turn with Waves: Wave Amplitude Versus Time



λ = 216 ft
a = 0.5 ft

Figure 24. Forty Knot Turn Comparison with and without Waves: Roll Versus Time

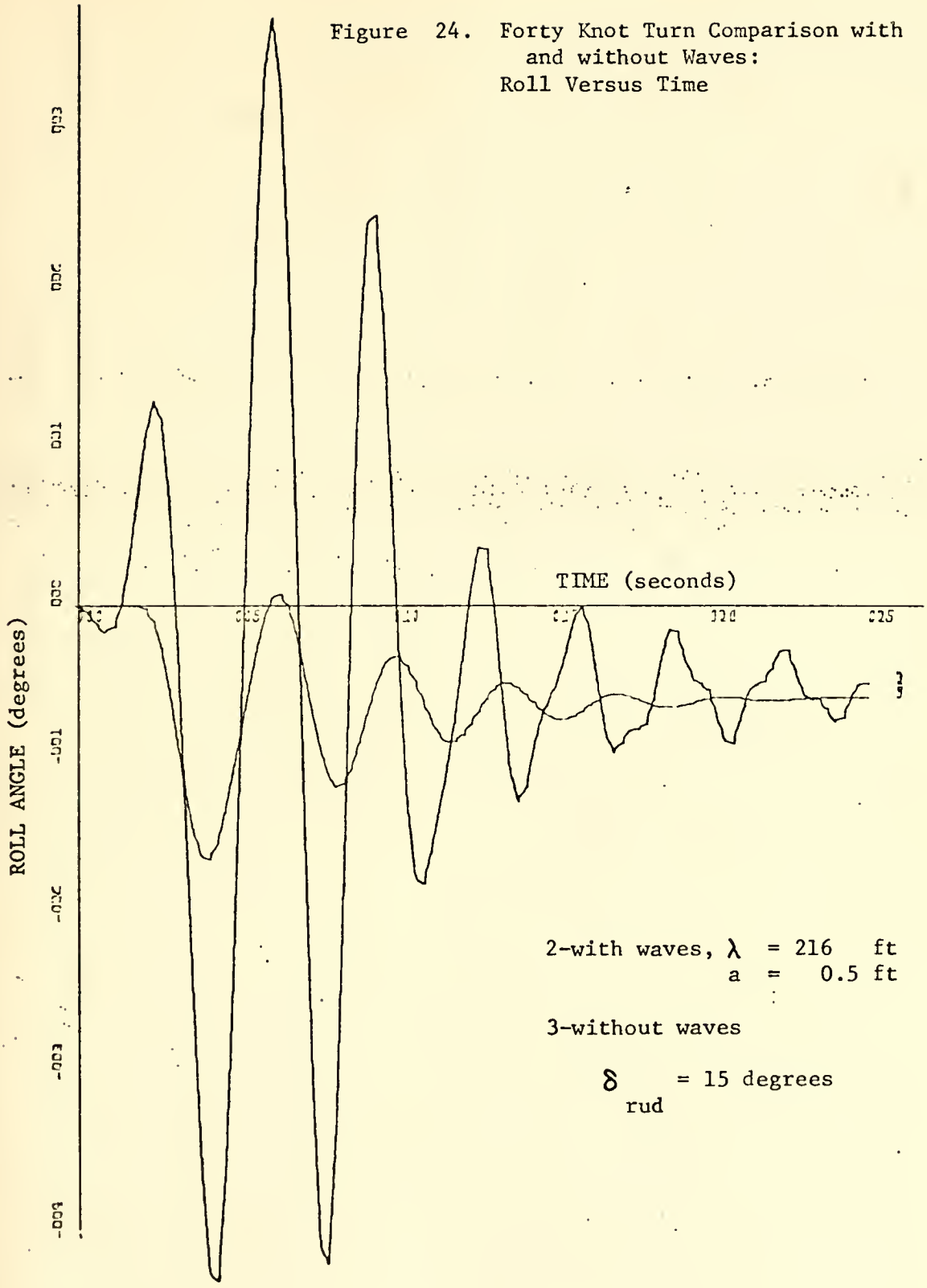
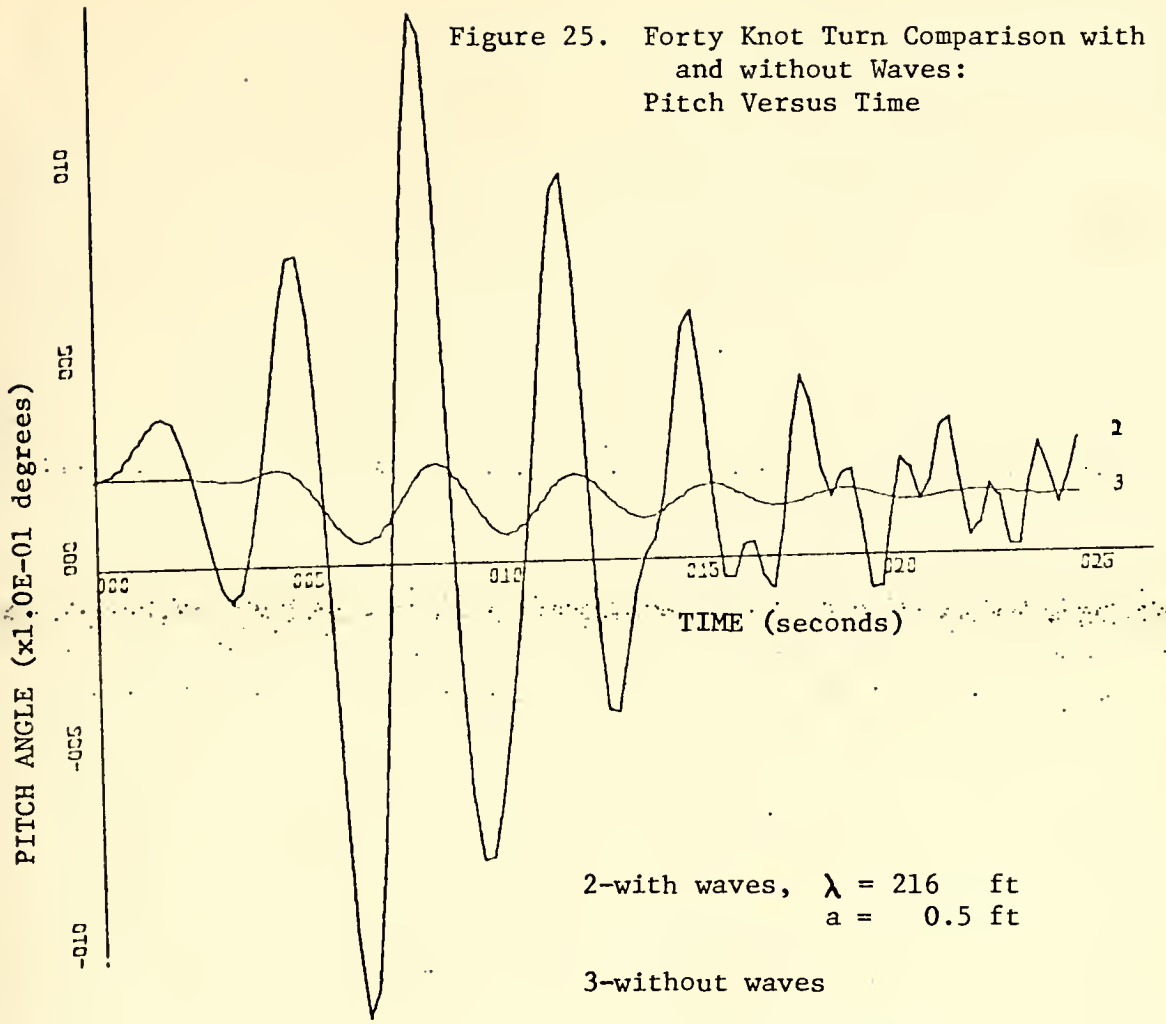


Figure 25. Forty Knot Turn Comparison with and without Waves: Pitch Versus Time



2-with waves, λ = 216 ft
a = 0.5 ft

3-without waves

δ_{rud} = 15 degrees

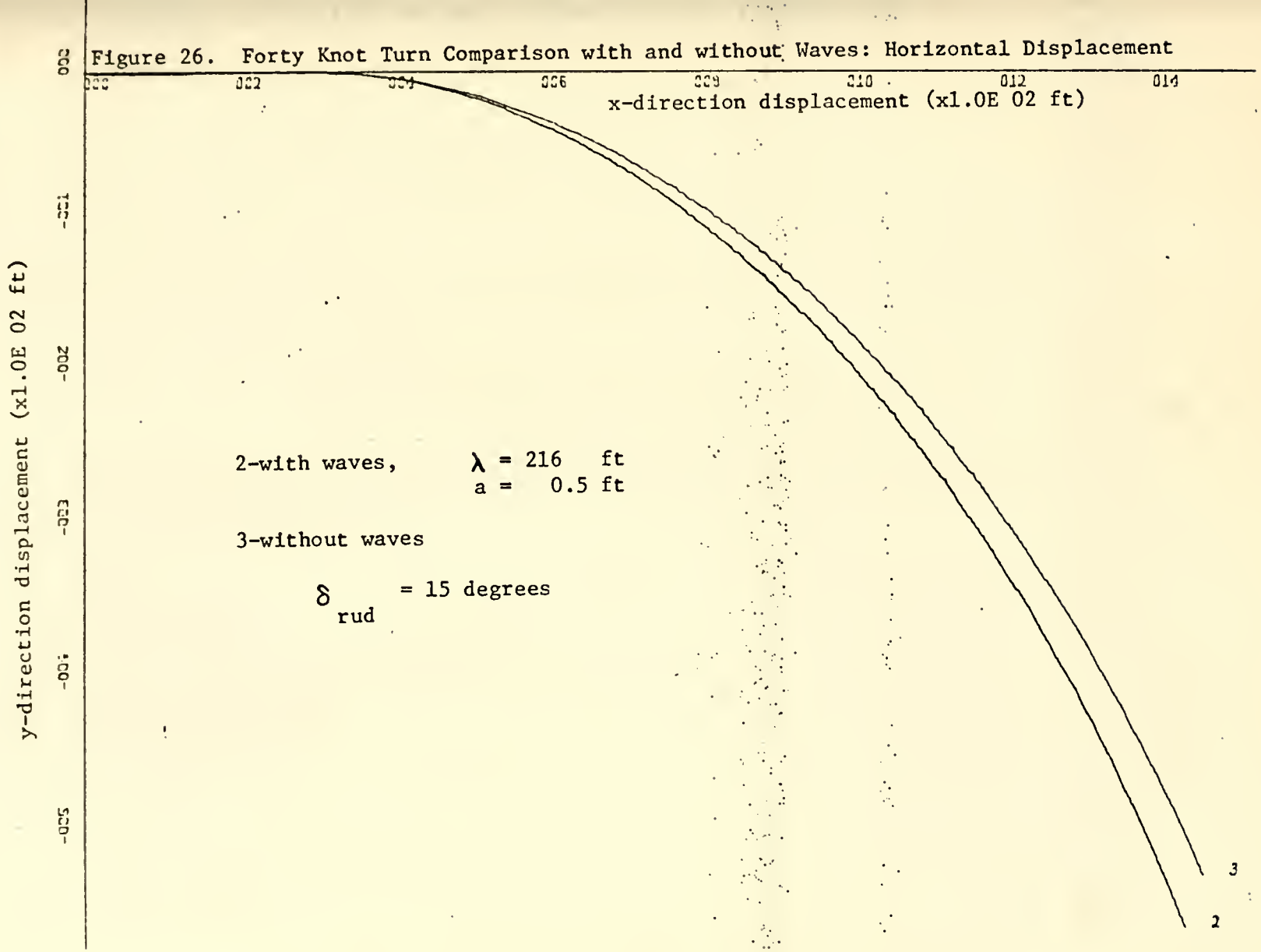


Figure 26. Forty Knot Turn Comparison with and without Waves: Horizontal Displacement
x-direction displacement (x1.0E 02 ft)
y-direction displacement (x1.0E 02 ft)
2-with waves, λ = 216 ft
a = 0.5 ft
3-without waves
δ rud = 15 degrees
3
2

```
OCEANIC COMPUTER SIMULATION OF BELL 100-B CAB/SES AS MODIFIED
      INTEGER ON                                                                00010
                                                                                00020
      COMMON /AIR/ PINF,RHOINF,GAM                                              10/26/72
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY00030
      COMMON /CONST/ PI,RAD,U0                                                  00040
      COMMON / ENGINE / TOUT,THRUST,THRSTO,STHRST,XP,YP,ZP                      00050
      COMMON /EQNCO/ NEQS,TOL(20),JQQ                                           6/4/73
      COMMON /FPROP/ FXP,FYP,FZP,FKP,FMP,FNP                                    00070
      COMMON / FROUDE / FN,FNCRIT                                               00080
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                             00090
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,          00100
     -IRUD,IPROP,IAEROD,IRHS                                                    00110
      COMMON /ROLL/ PHIMAX,TRCLL                                                00120
      COMMON /RUDDR/ DELRUD,RUDON,RUDOFF,RUDRAT,CCSRUD,XR,YR,ZR,TANRUD          00130
     1   ,RUDREV,IRDS,TL,RSPAN,RAREA,RASPR,RCLB,RTC                             00140
     2   ,RUDMAX,RRDRAT,RRDMAX                                                  2/24/73
      COMMON / VALOLD / YOLD(20)                                                00150
      COMMON /VARBLE/ VAL(40)                                                   00160
      COMMON /WAVE/ ETA(4,11),AW(10),CMEGA(10),DVCLW,NWAVE,BETA,                00170
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                         00180
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSEET,SINBET,PBBAR                  10/26/72
                                                                                00200
      EQUIVALENCE                (VAL(2),U),(VAL(3),V),(VAL(4),W),              00210
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),             00220
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),00230
     3(VAL(24),PB)                                                              00240
      DIMENSION DUMMY(20)                                                       10/26/72
                                                                                00250
      TC=1.0                                                                    10/26/72
      ON=1                                                                      00260
      PI=4.*ATAN(1.)                                                            00270
      RAD=180./PI                                                               00280
      WRITE(6,100)                                                              10/26/72
100   FORMAT(1H1//35X,22H LISTING OF INPUT DECK  //)                            10/26/72
99    READ(44,101,END=104) DUMMY                                                10/26/72
101   FORMAT(20A4)                                                              10/26/72
105   WRITE(6,102)DUMMY                                                         10/26/72
      WRITE(5,101) DUMMY                                                        10/26/72
102   FORMAT(5X,20A4)                                                           10/26/72
      GO TO 99                                                                  10/26/72
104   REWIND 5                                                                  10/26/72
                                                                                00290
11    CALL INCON(TIME)                                                          00300
      IF (IMM.EQ.3)  GO TO 605                                                  00310
                                                                                00320
      DO 10 J=1,20                                                              00330
 10   YOLD(J)=VAL(J+1)                                                          00340
```

```
      GO TO 2                                                                  00350
                                                                               00360
    1 CONTINUE                                                                 00370
      TOLD=TIME                                                                00380
      PBBAR=PBBAR*(1.-DELT/TC)+DELT*(PB-PINF)/TC                               10/26/72
      IF ( NWAVE.LE.0 )  GO TO 13                                              00390
      ZBAR=(1.-DELT/TC)*ZBAR+DELT*Z/TC                                         00400
      PHIBAR=(1.-DELT/TC)*PHIBAR+DELT*PHI/TC                                   00410
      THEBAR=(1.-DELT/TC)*THEBAR+DELT*THETA/TC                                 00420
      CALL WAVES(TIME)                                                         00430
                                                                               00440
   13 CALL SIDEWL                                                              00450
      CALL PROP                                                                00460
      CALL RUDDER                                                              00470
      CALL AEROD                                                               00480
      CALL INTGRL(TIME)                                                        00490
      IF(TIME.GT.FTIME) GO TO 12                                               00500
      IF ( FN.GT.FNCRIT) GO TO 14                                              00510
      PRINT 505                                                                00520
      GO TO 12                                                                 00530
                                                                               00540
   14 DELOLD=TIME-TOLD                                                         00550
      PSI=PSI+DELOLD*R                                                         00560
      X=X+DELOLD*(U*COS(PSI)-V*SIN(PSI))                                       00570
      Y=Y+DELOLD*(U*SIN(PSI)+V*COS(PSI))                                       00580
   15 IF (ABS(TIME-TPRINT) .LT. 1.E-6) GO TO 2                                 00590
      GO TO 1                                                                  00600
                                                                               00610
    2 CONTINUE                                                                 00620
      IF(ITRAJ .EQ. 0) GOTO 16                                                 00630
      DPHI=PHI*RAD                                                             00640
      DPSI=PSI*RAD                                                             00650
      DTHETA=THETA*RAD                                                         00660
      DP=P*RAD                                                                 00670
      DQ=Q*RAD                                                                 00680
      DR=R*RAD                                                                 00690
      WRITE (6,500) TIME,U,V,W,DP,DQ,DR,Z,DPHI,DTHETA,X,Y,DPSI                 00700
      BETS=(-V/U)*RAD                                                          00710
      DELRS=DELRUD*RAD                                                         00720
      WRITE(6,501) BETS,DELRS,FXP                                              00730
   16 CONTINUE                                                                 00740
      IMMTAG = (IMM+1)/2                                                       00750
      IF ( IMMTAG .EQ. 1  .AND. TIME.GE.BTIME-1.E-8 )  IMT = 1                 00760
      TPRINT=TPRINT+DELPNT                                                     00770
      ON=1                                                                     00780
      GO TO 1                                                                  00790
                                                                               00800
   12 CALL COLFIL                                                              00810
```

```
      IF (IMM.LT.1)  GO TO 11                                                   00820
      IF (IMM.NE.1)  GO TO 605                                                  00830
      END FILE IBMFIL                                                           00840
      GO TO 11                                                                  00850
  605 CALL SAM                                                                  00860
      GO TO 11                                                                  00870
  500 FORMAT(//10X,13HTIME (SEC) =  F6.2//10X,33HTRANSLATIONAL VELOCITIE00880
     1S (FT/SEC) /10X,2HU= F6.2,5X,2HV= F6.2,5X,2HW= F6.3//10X,31HROTATI00890
     2ONAL VELOCITIES (DEG/SEC) /10X,2HP= F6.2,5X,2HQ= F6.2,5X,2HR= F6.200900
     3//10X,30HDISPLACEMENTS (FT AND DEGREES) /10X,2HZ= F7.3,5X,4HPHI=   00910
     4F6.2,3X,6HTHETA= F6.2//10X,27HTRAJECTORY (FT AND DEGREES) /10X,    00920
     52HX= F8.2,4X,2HY= F8.2,4X,4HPSI= F8.2)                                00930
  501 FORMAT(1H0,9X,23HSIDESLIP ANGLE (DEG) =    F8.2,10X,21HRUDDER ANGLE00940
     1 (DEG) =  F8.3,10X,15HTHRUST (LBS) =   F12.1)                         00950
  505 FORMAT(///25X,28HCRAFT SPEED BELOW HUMP SPEED )                       00960
      END                                                                   00970


      SUBROUTINE AEROD                                                      00980
      INTEGER ON                                                            00990
      COMMON /FAERO/ FX,FY,FZ,FK,FM,FN                                      01000
      COMMON /FAIR/ RHOA,XLAERO                                             01010
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,      01020
     -IRUD,IPROP,IAEROD,IRHS                                                01030
      COMMON /VARBLE/ VAL(40)                                               01040
                                                                            01050
      EQUIVALENCE                (VAL(2),U),(VAL(3),V),(VAL(4),W),          01060
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),         01070
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),01080
     3(VAL(24),PB)                                                          01090
      QA=RHOA*U*U                                                           01100
      QAL=QA*XLAERO                                                         01110
      BETA=-V/U                                                             01120
      BETASQ=BETA*BETA                                                      01130
      FX=-(.71812*BETASQ+.063)*QA                                           01140
      FY=(.82073*BETASQ+.45837*BETA)*QA                                     01150
      FZ=-(.20517*BETASQ+0.210)*QA                                          01160
      FK=0.0                                                                01170
      FM=.022*QAL                                                           01190
      FN=(-.61551*BETASQ+.32945*BETA)*QAL                                   01200
                                                                            01210
      IF (IAEROD.NE.ON) RETURN                                              01220
                        WRITE(6,100) FX,FY,FZ,FK,FM,FN                      01230
  100 FORMAT(/10X,23HAEROD FX,FY,FZ,FK,FM,FN/6E15.4)                        01240
      RETURN                                                                01250
      END                                                                   01260
```

```
      SUBROUTINE BOWSL                                                  01270
      INTEGER ON                                                        01280
      COMMON /AIR/ PINF,RHOINF,GAM                                      01290
      COMMON /CONST/ PI,RAD,UO                                          01300
      COMMON / FORBS/ FX,FY,FZ,FK,FM,FN,CL                              01310
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM     01320
     1,CELS(4,10),XCP,ZCP                                               01330
      COMMON /GEOMBS/DETABX(11),DETABT(11),ARM1B(10),ARM2B(10)          01340
     1 ,DFBS(10),TSKIB(10)                                              01350
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,  01360
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO       01370
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,  01380
     -IRUD,IPROP,IAEROD,IRHS                                            01390
      COMMON /SOFTBS/DSBS,CFBS,PBS,DPBS,YAVGB(10),DELYBS(10),ELMAXB     01400
      COMMON /VARBLE/ VAL(40)                                           01410
      COMMON /WAVE/ ETA(4,11),AW(10),CMEGA(10),DVOLW,NWAVE,BETA,        01420
     1               FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                01430
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR          10/26/72
      DIMENSION GAP(11),ELSKI(11)                                       01450
      DIMENSION WTAB(6),ZTAB(6)                                         01460
      DATA NPTS,IBS/6,0/                                                01470
      DATA WTAB/0.0,3.75,5.42,6.67,7.5,8.42/                            01480
      DATA ZTAB/3.75,4.00,4.42,4.83,5.25,5.67/                          01490
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),       01500
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     01510
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),01520
     3(VAL(24),PB)                                                      01530
      DATA ENU /1.28E-5/                                                01540
      DO 5 J=1,11                                                       01550
      GAP(J)=0.0                                                        01560
      ELSKI(J)=0.0                                                      01570
    5 CONTINUE                                                          01580
      FX=0.0                                                            01590
      FZ=0.0                                                            01600
      FK=0.0                                                            01610
      FM=0.0                                                            01620
      FN=0.0                                                            01630
      ALBS=0.0                                                          01640
      PBAR=PB-PINF                                                      01650
      DELP=PBAR                                                         01660
      IF (DELP.LT.0.0) DELP=0.0                                         01670
      N=NSTA(3)                                                         01680
      DO 1 K=1,N                                                        01690
      GAP(K)=-(Z+ZS-XX(3,K)*THETA+YY(3,K)*PHI+ETA(3,K))                 01700
      ELSKI(K)=-GAP(K)                                                  01710
      IF (GAP(K) .LT. 0.0) GAP(K)=0.0                                   01720
    1 CONTINUE                                                          01730
      N=N-1                                                             01740
```

```
      DO 2 K=1,N                                                        01750
      ELSKIA=(ELSKI(K+1)+ELSKI(K))/2.                                   01760
      IF (ELSKIA.LE.0.0) GO TO 15                                       01770
      DFBS(K)=0.0                                                       01780
      IF(ELSKIA.LT.ELMAXB) GO TO 10                                     01790
      DELPBG=PBS-PB                                                     01800
      IF (DELPBG.LT.0.0) DELPBG=0.0                                     01810
      DY=ELMAXB-ELSKIA                                                  01820
      ELBAG=FGI(ELSKIA,NPTS,ZTAB,WTAB,IBS)                              01830
      ELSKIA=ELMAXB                                                     01840
      DFBS(K)=-DELPBG*ELBAG*DSBS                                        01850
   10 CONTINUE                                                          01860
      ARM1B(K)=XX(3,K)+ELSKIA/2.*DELYBS(K)/DSBS                         01870
      ARM2B(K)=ZS-ELSKIA                                                01880
      DFBS(K)=-DELP*ELSKIA*DSBS+DFBS(K)                                 01890
      ARG=.5*RHO*U*U*ELSKIA*DSBS                                        01900
      RESKI=U*ELSKIA/ENU*DSBS/DELYBS(K)                                 01910
      CDTSKI = .427/(ALOG10(RESKI) - .407 )**2.64                       01920
      TSKIB(K)=-ARG*CDTSKI                                              01930
      GO TO 18                                                          01940
   15 DFBS(K)=0.0                                                       01950
      TSKIB(K)=0.0                                                      01960
   18 CONTINUE                                                          01970
      FX=FX+TSKIB(K)                                                    01980
      FZ=FZ+DFBS(K)                                                     01990
      FK=FK+DFBS(K)*YAVGB(K)                                            02000
      FM=FM-DFBS(K)*ARM1B(K)+TSKIB(K)*ARM2B(K)                          02010
      FN=FN-TSKIB(K)*YAVGB(K)                                           02020
      ALBS=ALBS+(GAP(K)+GAP(K+1))/2.*DSBS                               02030
    2 CONTINUE                                                          02040
      QL=CFBS*ALBS*SQRT(2.*ABS(PBAR)/RHOINF)*SIGN(1.,PBAR)              02050
      IF (IBOWSL .NE. ON) RETURN                                        02060
      WRITE (6,100) GAP,ELSKI,FX,FY,FZ,FK,FM,FN                         02070
  100 FORMAT(//10X,8HBOW SEAL /26H GAP (FT.) (PORT TO STBD.) /11F10.5   02080
     1/28H ELSKI (FT.) (PORT TO STBD.) /11F10.5 /10X,23HBOWSL FX,FY,FZ,F02090
     2K,FM,FN /6E15.4)                                                  02100
      RETURN                                                            02110
      END                                                               02120


      SUBROUTINE COLFIL                                                 02130
******NOTE ALL LINES BEGINNING****SES/BH8*****
      COMMON /COLUMN/ IVERT,ILATRL                                      02140
      COMMON/PLVCQQ/NVI,NVD,NLI,NLD
      DIMENSION PVQQ(25),XOUT(900),YOUT(900)                            20/4/73
      EQUIVALENCE (PVQQ(1),TIME),(PVQQ(2),WVAMP),(PVQQ(3),ZD),          20/4/73
     1(PVQQ(4),THETA),(PVQQ(5),PB),(PVQQ(6),SUMFX),(PVQQ(7),SUMFY),(PVQQ20/4/73
     2(8),SUMFZ),(PVQQ(9),SUMMX),(PVQQ(10),SUMMY),(PVQQ(11),SUMMZ),     20/4/73
```

```
     3(PVQQ(12),U),(PVQQ(13),V),(PVQQ(14),W),(PVCC(15),P),(PVQQ(16),Q),  20/4/73
     4(PVQQ(17),R),(PVQQ(18),PHI),(PVQQ(19),BETA),(PVQQ(20),X),          20/4/73
     5(PVQQ(21),Y),(PVQQ(22),Z),(PVQQ(23),PSI)                           20/4/73
*****EQUIVALENCE (PVQQ(1),TIME),(PVQQ(2),ZD),(PVCQ(3),THETA),            2/5/73
*****1(PVQQ(4),PB),(PVQQ(5),SUMMX),(PVQQ(6),FKBS),(PVQQ(7),FKSS),        2/5/73
*****2(PVQQ(8),FKSW),(PVQQ(9),FKRUD),(PVQQ(10),FKP),(PVCQ(11),FKP),      2/5/73
*****3(PVQQ(12),U),(PVQQ(13),V),(PVQQ(14),W),(PVCC(15),P),(PVQQ(16),Q),  20/4/73
*****4(PVQQ(17),R),(PVQQ(18),PHI),(PVQC(19),BETA),(PVQQ(20),X),          20/4/73
      IF (IVERT.NE.1) GO TO 11
       ENDFILE 1                                                         02160
      REWIND 1                                                           02170
      IQ=0
      WRITE(6,100)                                                       02180
    7 READ(1,END=10)TIME,WVAMP,ZD,THETA,PB,SUMFX,SUMFY,SUMFZ,SUMMX,SUMMY20/4/73
     1,SUMMZ                                                             20/4/73
****7 READ(1,END=10)TIME,ZD,THETA,PB,SUMMX,FKBS,FKSS,FKSW,FKRUD,FKP,     2/5/73
*****5(PVQQ(21),Y),(PVQQ(22),Z),(PVQQ(23),PSI)                           20/4/73
   50 WRITE(6,200)  TIME,WVAMP,ZD,THETA,PB,SUMFX,SUMFY,SUMFZ,SUMMX,SUMMY20/4/73
     1,SUMMZ                                                             20/4/73
***50 WRITE(6,200)  TIME,ZD,THETA,PB,SUMMX,FKBS,FKSS,FKSW,FKRUD,FKP,     2/5/73
*****1FKWAV,FKAED,FKBUB                                                  2/5/73
      IF(IQ.GE.900) GO TO 7
      IQ=IQ + 1
      XCUT(IQ)=PVQQ(NVI)
      YOUT(IQ)=PVQQ(NVD)
      GO TO 7                                                            02210
   10 IF (NVI .LT. 1 .OR. NVD .LT. 1 ) GO TO 11                          2/15/73
      WRITE (6,510) NVD,NVI                                              3/3/73
      CALL PLOTP (XOUT,YOUT,-IQ,0)                                       2/73
   11 IF (ILATRL.NE.1) GO TO 40
      ENDFILE 2                                                          02230
      REWIND 2                                                           02240
      IQ=0
      WRITE(6,300)                                                       02250
    5 READ(2,END=15) TIME,U,V,W,P,Q,R,PHI,BETA,X,Y,Z,PSI                 19/4/73
   20 WRITE(6,400)   TIME,U,V,W,P,Q,R,PHI,BETA,X,Y,Z,PSI                 19/4/73
      IF(IQ.GE.900) GO TO 5
      IQ=IQ + 1
      XCUT(IQ)=PVQQ(NLI)
      YOUT(IQ)=PVQQ(NLD)
      GO TO 5                                                            02280
   15 IF (NLI .LT. 1 .OR. NLD .LT. 1 ) GO TO 12                          2/15/73
      WRITE (6,510) NLD,NLI                                              3/3/73
      CALL PLOTP (XOUT,YOUT,-IQ,0)                                       2/73
   12 GO TO 40                                                           2/73
  300 FORMAT(1H1/53X,'SUMMARY PLOT TWO',//2X,'TIME',5X,'U',9X,'V',9X,'W'19/4/73
     1,9X,'P',9X,'Q',9X,'R',8X,'PHI',5X,'BETA',9X,'X',10X,'Y',9X,'Z',6X,19/4/73
     2'PSI')                                                             19/4/73
```

```
  400 FORMAT(1X,F6.2,3X,F6.2,7(3X,F7.3),3X,F7.1,3X,F8.1,3X,F5.1,3X,F6.1)19/4/73
**400 FORMAT(1X,F6.2,3X,F6.2,7(3X,F7.3),3X,F7.1,3X,F8.1,3X,F5.1,3X,F6.1)19/4/73
  100 FORMAT(1H1/53X,'SUMMARY PLOT ONE',//2X,'TIME',3X,'WAVE AMP',3X,'DR19/4/73
     1AFT',3X,'THETA',2X,'GAGE PRES',3X,'SUM FX',9X,'SUM FY',8X,'SUM FZ'20/4/73
     2,8X,'SUM MX',8X,'SUM MY',8X,'SUM MZ')                          20/4/73
**100 FORMAT(1H1/53X,'SUMMARY PLOT ONE',//2X,'TIME',5X,'DRAFT',3X,    2/5/73
*****1'THETA',2X,'GAGE PRES',3X,'SUM MX=',5X,'MBOWSL+',3X,' MSTNSL+',  2/7/73
*****23X,'MSDWAL+',4X,'MRUD+',4X,'MPROP+',4X,'MWAV+',5X,'MAERO+',4X,   2/5/73
*****3'MBUB')                                                        2/5/73
  200 FORMAT(1X,F6.2,3X,F6.3,3X,F6.2,2X,F6.2,3X,F6.1,6(3X,F11.3))
**200 FORMAT(1X,F6.2,3X,F6.3,3X,F6.2,2X,F6.2,3X,F11.3,8(1X,F9.1))     7/5/73
   40 REWIND 1                                                       02380
      REWIND 2                                                       02390
      WRITE(6,500)                                                   02400
  500 FORMAT(1H1)                                                    02410
  510 FORMAT(////'DEPENDENT VARIABLE',I5,2X,                         3/5/73
     1'VERSUS INDEPENDENT VARIABLE',I5///)                           3/5/73
      RETURN                                                         02420
      END                                                            02430


      SUBROUTINE DMINV (A,N,D)                                       02440
      DIMENSION A(6,6),PIVOT(6)                                      02450
      DIMENSION IPVOT(6),INDEX(6,2)                                  02460
      EQUIVALENCE (IROW,JROW),(ICOL,JCOL)                            02470
      D=1.0                                                          02480
      DO 17 J=1,N                                                    02490
      IPVOT(J)=0                                                     02500
   17 CONTINUE                                                       02510
      DO 135 I=1,N                                                   02520
      T=0.0                                                          02530
        DO 9 J=1,N                                                   02540
      IF(IPVOT(J)-1) 13,9,13                                         02550
   13 DO 23 K=1,N                                                    02560
      IF(IPVOT(K)-1) 43,23,81                                        02570
   43 IF (ABS(T)-ABS(A(J,K))) 83,23,23                               02580
   83 IROW=J                                                         02590
      ICOL=K                                                         02600
      T=A(J,K)                                                       02610
   23 CONTINUE                                                       02620
    9 CONTINUE                                                       02630
      IPVOT(ICOL)=IPVOT(ICOL)+1                                      02640
      IF(IROW-ICOL) 73,109,73                                        02650
   73 D=-D                                                           02660
      DO 12 L=1,N                                                    02670
      T=A(IROW,L)                                                    02680
      A(IROW,L)=A(ICOL,L)                                            02690
      A(ICOL,L)=T                                                    02700
```

```
 12   CONTINUE                                                                  02710
109   INDEX(I,1)=IROW                                                           02720
      INDEX(I,2)=ICOL                                                           02730
      PIVOT(I)=A(ICOL,ICOL)                                                     02740
      D=D*PIVOT(I)                                                              02750
      A(ICOL,ICOL)=1.0                                                          02760
      DO 205 L=1,N                                                              02770
      A(ICOL,L)=A(ICOL,L)/PIVOT(I)                                              02780
205   CONTINUE                                                                  02790
      DO 134 LI=1,N                                                             02800
      IF(LI-ICOL) 21,134,21                                                     02810
 21   T=A(LI,ICOL)                                                              02820
      A(LI,ICOL)=0.0                                                            02830
      DO 89 L=1,N                                                               02840
      A(LI,L)=A(LI,L)-A(ICOL,L)*T                                               02850
 89   CONTINUE                                                                  02860
134   CONTINUE                                                                  02870
135   CONTINUE                                                                  02880
      DO 3 I=1,N                                                                02890
      L=N-I+1                                                                   02900
      IF(INDEX(L,1)-INDEX(L,2)) 19,3,19                                         02910
 19   JROW=INDEX(L,1)                                                           02920
      JCOL=INDEX(L,2)                                                           02930
      DO 549 K=1,N                                                              02940
      T=A(K,JROW)                                                               02950
      A(K,JROW)=A(K,JCOL)                                                       02960
      A(K,JCOL)=T                                                               02970
549   CONTINUE                                                                  02980
  3   CONTINUE                                                                  02990
 81   RETURN                                                                    03000
      END                                                                       03010


      SUBROUTINE FAN                                                            03020
      INTEGER ON                                                                03030
      COMMON /AIR/ PINF,RHOINF,GAM                                              03040
      COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,           03050
     1 ENSFAN,BRPM,EMRPM,SRPM,NPTSB,NPTSM,NPTSS                                 03060
     2 ,PBFAN(25),PMFAN(25),PSFAN(25)                                           03070
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,          03080
     -IRUD,IPROP,IAEROD,IRHS                                                    03090
      COMMON /SOFTBS/DSBS,CFBS,PBS,DPBS,YAVGB(10),DELYBS(10),ELMAXB             03100
      COMMON /SOFTSS/ XLF,PSS,SINTH,CCSTH,XSS,ZSS,DELYSS,DPSS                   03110
     1 ,ELMAXS,YAVGS(10)                                                        03120
      COMMON /VARBLE/ VAL(40)                                                   03130
      DIMENSION QB(1),QM(1),QS(1),PBOW(1),PM(1),PS(1)                           03140
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),               03150
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),             03160
```

```
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),03170
     3(VAL(24),PB)                                                       03180
      EQUIVALENCE (VAL(18),FANPWR)                                       03190
      EQUIVALENCE (QBFAN(1),QB(1)),(QMFAN(1),QM(1)),(QSFAN(1),QS(1)),    03200
     1 (PBFAN(1),PBOW(1)),(PMFAN(1),PM(1)),(PSFAN(1),PS(1))              03210
                                                                         03220
      BRAT=1700./BRPM                                                    03230
      EMRAT=1700./EMRPM                                                  03240
      SRAT=1870./SRPM                                                    03250
      PB1=PBS-PINF                                                       03260
      PB2=PB-PINF                                                        03270
      PB3=PSS-PINF                                                       03280
      PBARB=PB1*BRAT**2                                                  03290
      PBARM=PB2*EMRAT**2                                                 03300
      PBARS=PB3*SRAT**2                                                  03310
                                                                         03320
      QBOW=ENBFAN*FG1(PBARB,NPTSB,PBOW,QB,IB)/BRAT                       03330
      QMAIN=ENMFAN*FG1(PBARM,NPTSM,PM,QM,IM)/EMRAT                       03340
      QSTN=ENSFAN*FG1(PBARS,NPTSS,PS,QS,IS)/SRAT                         03350
      QIN=QBOW+QMAIN+QSTN                                                03360
      FANPWR=(QBOW*PB1+QMAIN*PB2+QSTN*PB3)/550.                          03370
      IF (IRHS.NE.ON) RETURN                                             03380
      WRITE(6,100) QBOW,QMAIN,QSTN,PBARB,PBARM,PBARS                     03390
  100 FORMAT(//4H FAN /32H Q - BOW,MAIN,STERN (CU FT /SEC) 3F12.1        03400
     1 /28H DELP - BOW,MAIN,STERN (PSF) 3F11.2)                          03410
      RETURN                                                             03420
      END                                                                03430


      FUNCTION FG1(X,N,XT,YT,IX)                                         03440
      DIMENSION XT(1),YT(1)                                              03450
      IF (IX.LT.1) IX=1                                                  03460
      IF (IX.GT.N-1) IX=N-1                                              03470
      I=SIGN(1.0,X-XT(IX))                                               03480
   10 IF (IX.LT.1 .OR. IX.GE.N) GO TO 30                                 03490
      IF (XT(IX).GT.X .OR. X.GT.XT(IX+1)) GO TO 20                       03500
      C=(X-XT(IX))/(XT(IX+1)-XT(IX))                                     03510
      GO TO 100                                                          03520
   20 IX=IX+I                                                            03530
      GO TO 10                                                           03540
   30 C=IX/N                                                             03550
      IX=IX-1                                                            03560
  100 FG1=YT(IX)+C*(YT(IX+1)-YT(IX))                                     03570
      RETURN                                                             03580
      END                                                                03590
```

```
      SUBROUTINE FORIT(FNT,N,M,A,B,IER)                                 03600
                                                                        03610
      DIMENSION A(1),B(1),FNT(1)                                        03620
                                                                        03630
C     CHECK FOR PARAMETER ERRORS                                        03640
      IER=0                                                             03650
20    IF(M) 30,40,40                                                    03660
30    IER=2                                                             03670
      RETURN                                                            03680
40    IF(M-N) 60,60,50                                                  03690
50    IER=1                                                             03700
      RETURN                                                            03710
                                                                        03720
C     COMPUTE AND PRESET CONSTANTS                                      03730
 60   CONTINUE                                                          03740
      AN=N                                                              03750
      COEF=2.0/(2.0*AN+1.0)                                             03760
      PI=4.*ATAN(1.)                                                    03770
      CONST=PI*COEF                                                     03780
      S1=SIN(CONST)                                                     03790
      C1=COS(CONST)                                                     03800
      C=1.0                                                             03810
      S=0.0                                                             03820
      J=1                                                               03830
      FNTZ=FNT(1)                                                       03840
70    U2=0.0                                                            03850
      U1=0.0                                                            03860
      I=2*N+1                                                           03870
                                                                        03880
C     FORM FOURIER COEFFICIENTS RECURSIVELY                             03890
75    U0=FNT(I)+2.0*C*U1-U2                                             03900
      U2=U1                                                             03910
      U1=U0                                                             03920
      I=I-1                                                             03930
      IF(I-1) 80,80,75                                                  03940
80    A(J)=COEF *(FNTZ+ C*U1-U2)                                        03950
      B(J)=COEF*S*U1                                                    03960
      IF(J-(M+1)) 90,100,100                                            03970
90    Q=C1*C-S1*S                                                       03980
      S=C1*S+S1*C                                                       03990
      C=Q                                                               04000
      J=J+1                                                             04010
      GO TO 70                                                          04020
                                                                        04030
100   A(1)=A(1)*0.5                                                     04040
      RETURN                                                            04050
      END                                                               04060
```

```
      SUBROUTINE INCON (TIME)                                                   04070
      INTEGER ON                                                                04080
      COMMON /AIR/ PINF,RHOINF,GAM                                              04090
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY04100
      COMMON /COLUMN/ IVERT,ILATRL                                              04110
      COMMON /CONST/ PI,RAD,UO                                                  04120
      COMMON /CNTRL/CONTW,CONTQ,CONTTH,QMULT,LOUVER,ACONTZ,ACONTW,ZEQUIL04130
     1 ,THEQL,ACBASE                                                            04140
      COMMON / ENGINE / TOUT,THRUST,THRSTO,STHRST,XP,YP,ZP                      04150
      COMMON /EQNCO/ NEQS,TCL(20),JQQ                                           6/4/73
      COMMON /FAIR/ RHOA,XLAERO                                                 04170
      COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,           04180
     1 ENSFAN,BRPM,EMRPM,SRPM,NPTSB,NPTSM,NPTSS                                 04190
     2 ,PBFAN(25),PMFAN(25),PSFAN(25)                                           04200
      COMMON / FROUDE / FN,FNCRIT                                               04210
      COMMON/GBOW/ XBOW                                                         04220
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VCLNOM             04230
     1,CELS(4,10),XCP,ZCP                                                       04240
      COMMON /GEOMSW/ XAVG(10),DS                                               04250
      COMMON /PWAVE/ FNCON,PWVCON                                               04260
      COMMON/LEAKER/ ALEAK,CFSS                                                 04270
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,          04280
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO               04290
      COMMON /MATRIX/ A(6,6)                                                    04300
      COMMON /OPTION/ I3DOF,ISRGE,ITRIM                                         04310
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT                                       04320
      COMMON/PLVCOC/NVI,NVO,NLI,NLO                                             04330
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                             04340
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,          04350
     -IRUD,IPROP,IAEROD,IRHS                                                    04360
      COMMON /ROLL/ PHIMAX,TROLL                                                04370
      COMMON /RUDDR/ DELRUD,RUDON,RUDOFF,RUDRAT,COSRUD,XR,YR,ZR,TANRUD          04380
     1  ,RUDREV,IRDS,TL,RSPAN,RAREA,RASPR,RCLB,PTC                              2/24/73
     2  ,RUDMAX,RRDRAT,RRDMAX                                                   04390
      COMMON /RISER/ AMPTC                                                      04400
      COMMON /SOFTBS/DSBS,CFBS,PBS,DPBS,YAVGB(10),DELYBS(10),ELMAXB             04410
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS                   04420
     1 ,ELMAXS,YAVGS(10)                                                        04430
      COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSW04440
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC             04450
      COMMON /STABLE/ S(4),ISTAB                                                04460
      COMMON /STSLR/ CPHI,CPHID                                                 04470
      COMMON / VALOLD / YOLD(20)                                                04480
      COMMON /VARBLE/ VAL(40)                                                   04490
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVOLW,NWAVE,BETA,                04500
     1               FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                        10/26/72
     2               ,ZBAR,PHIBAR,THEBAR,TC,COSEET,SINBET,PBBAR                 04520
      COMMON /WAVEF/WAVLEN(10),OMEGAE(10),WAVSLP(10),ENCPER(10)                 04530
```

```
      COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,    04530
     1           AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),         04540
     2           AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                      04550
     3           ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                   04560
     4           AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),         04570
     5           AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                      04580
     6           ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)                    04590
     7           ,B3(36),XREF,RX                                          04600
                                                                          04610
      DIMENSION ZZZ(14050)                                                04620
      EQUIVALENCE (ZZZ,NAL)                                               04630
      EQUIVALENCE                    (VAL(2),U),(VAL(3),V),(VAL(4),W),    04640
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),       04650
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),  04660
     3(VAL(24),PB)                                                        04670
      DIMENSION TEMP(7),XMO(10)                                           04680
      DIMENSION TITLE(20)                                                 04690
      DATA BEAM,BETAD,DELO,DELPI,DLRDO,DSO,ISYS,RMAXO,RONO,RRATO,RREVO,   04700
     1 THETO,THSSI,TPRINO,UO,VXO,VZO,XBSI,XCPO,XLTCT,XPO,XRO,XSSI,YPO,    04710
     2 ZPO,ZRO,ZSSI/ 6*0.0,0,20*0.0/                                      04720
                                                                          04730
      TOUT=1.E6                                                           04740
      PINF=2116.                                                          04750
      RHOINF=.002378                                                      04760
      GAM=1.4                                                             04770
10    READ(5,99) ISYSL,IOPT,(TEMP(I),I=1,7)                               04780
      IF( ISYSL .EQ. ISYS .AND. ISYSL.EQ. 13) GOTO 70                     04790
      ISYS=ISYSL                                                          04800
      IF(ISYS .LE. 0 .OR.ISYS .GE. 20) GOTO 70                            04810
      GOTO(100,200,300,400,500,600,700,800,900,1000,1100,1200,1300,       04820
     1          1400,1500,1600,1700,1800,1900),ISYS                       04830
                                                                          04840
C     PROGRAM CONTROL PARAMETERS                                          04850
100   CONTINUE                                                            04860
      GOTO (101,102,103,104,105),IOPT                                     04870
 101  CONTINUE                                                            04880
      STIME=TEMP(1)                                                       04890
      FTIME=TEMP(2)                                                       04900
      DELO=TEMP(3)                                                        04910
      DELPNT=TEMP(4)                                                      04920
      TPRINO=TEMP(5)                                                      04930
      IF (TPRINO.LT.STIME+DELPNT)  TPRINO = STIME+DELPNT                  04940
      IF (DELO.GT.DELPNT) DELO=DELPNT                                     04950
      IF (DELO.EQ.0.0) GO TO 140                                          04960
      GOTO 10                                                             04970
102   READ (5,191) IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IRUD,    04980
     1 IPROP,IAEROD,IRHS                                                  04990
      GOTO 10                                                             05000
```

```
103   READ (5,175) NEQS,JQQ,(TOL(J),J=1,NEQS)                    2/14/73
      GOTO 10                                                     05020
 104  READ(5,191) IVERT,ILATRL,NVC,NVI,NLC,NLI
      GO TO 10                                                    05040
 105  CONTINUE                                                    05050
      I3DOF=TEMP(1)                                               05060
      ISRGE=TEMP(2)                                               05070
      ITRIM=TEMP(3)                                               05080
      GO TO 10                                                    05090
 140  WRITE(6,195)                                                05100
      STOP                                                        05110
                                                                  05120
C     MASS DISTRIBUTION                                           05130
 200  G=32.17                                                     05140
      RHO=1.99                                                    05150
      HRHO=RHO/2.                                                 05160
      GO TO (210,220,230), IOPT                                   05170
 210  IMM = 0                                                     05180
      WEIGHT = TEMP(1)                                            05190
      AM = WEIGHT/G                                               05200
      XS = TEMP(2)                                                05210
      ZS = TEMP(3)                                                05220
      AIXX = TEMP(4)                                              05230
      AIYY = TEMP(5)                                              05240
      AIZZ = TEMP(6)                                              05250
      AIXZ = TEMP(7)                                              05260
C     INERTIA MATRIX OPERATIONS                                   05270
 212  DO 211 I=1,6                                                05280
      DO 211 N=1,6                                                05290
 211  A(I,N) = 0.0                                                05300
      DO 213 N=1,3                                                05310
 213  A(N,N)=AM                                                   05320
      A(4,4)=AIXX                                                 05330
      A(5,5)=AIYY                                                 05340
      A(6,6)=AIZZ                                                 05350
      A(4,6)=-AIXZ                                                05360
      A(6,4)=-AIXZ                                                05370
      AIMAX=AMAX1(AM,AIXX,AIYY,AIZZ,ABS(AIXZ))                    05380
      DO 214 I=1,6                                                05390
      DO 214 J=1,6                                                05400
 214  A(I,J)=A(I,J)/AIMAX                                         05410
      CALL DMINV (A,6,D)                                          05420
      DO 215 I=1,6                                                05430
      DO 215 J=1,6                                                05440
 215  A(I,J)=A(I,J)/AIMAX                                         05450
      IF (D.NE.0.0) GO TO 10                                      05460
      WRITE (6,216)                                               05470
      STOP                                                        05480
```

```
C      READ WEIGHT DISTRIBUTION - ASSUME TRANSVERSE (PORT/STBD) SYMMETRY 05490
C         X INPUT DIST. FWD. OF (SIDEWALL) TRANSCM                       05500
C         Y INPUT DIST. TO STARBOARD                                     05510
  220 I = 1                                                              05520
C           Z INPUT DIST. UP FROM KEEL-LINE                              05530
  222 READ (5,192) AMI(I),XI(I),YI(I),ZI(I)                              05540
      IF (AMI(I).LT.0.0)  GO TO 224                                      05550
      I = I+1                                                            05560
      IF ( I.GT.201 )  GO TO 70                                          05570
      GO TO 222                                                          05580
  224 NMASS = I-1                                                        05590
      SUM = 0.0                                                          05600
      SUX = 0.0                                                          05610
      SUZ = 0.0                                                          05620
      DO 225 I=1,NMASS                                                   05630
      AMI(I) = AMI(I)/G                                                  05640
      SUM = SUM+AMI(I)                                                   05650
      SUX = SUX+AMI(I)*XI(I)                                             05660
  225 SUZ = SUZ+AMI(I)*ZI(I)                                             05670
      AM = SUM*2.0                                                       05680
      WEIGHT = AM*G                                                      05690
      XS  = SUX/SUM                                                      05700
      ZS  = SUZ/SUM                                                      05710
      SUM = 0.0                                                          05720
      SUX = 0.0                                                          05730
      SUY = 0.0                                                          05740
      SUZ = 0.0                                                          05750
      DO 226 I=1,NMASS                                                   05760
      XI(I) = XI(I)-XS                                                   05770
      ZI(I) = -ZI(I)+ZS                                                  05780
      AMK = AMI(I)*2.0                                                   05790
      SUX = SUX+AMK*XI(I)*XI(I)                                          05800
      SUY = SUY+AMK*YI(I)*YI(I)                                          05810
      SUZ = SUZ+AMK*ZI(I)*ZI(I)                                          05820
  226 SUM = SUM+AMK*XI(I)*ZI(I)                                          05830
      AIXX = SUY+SUZ                                                     05840
      AIYY = SUX+SUZ                                                     05850
      AIZZ = SUX+SUY                                                     05860
      AIXZ = SUM                                                         05870
      GO TO 212                                                          05880
  230 GO TO 10                                                           05890
                                                                         05900
C      XX AND YY TABLES                                                  05910
  300 CONTINUE                                                           05920
      NSTA(1) = TEMP(1)                                                  05930
      NSTA(2) = TEMP(2)                                                  05940
      NSTA(3) = TEMP(3)                                                  05950
      NSTA(4) = TEMP(4)                                                  05960
```

```
      XLTOT=TEMP(5)                                                     05970
      GOTO 10                                                           05980
                                                                        05990
C     SIDEWALL (INCLUDING APPENDAGES)                                   06000
400   CONTINUE                                                          06010
      GOTO (401,402),IOPT                                               06020
401   YSW=TEMP(1)                                                       06030
      XLSW=TEMP(2)                                                      06040
      CFSW=TEMP(3)                                                      06050
      CDSW=TEMP(4)                                                      06060
      AVBMSW=TEMP(5)                                                    06070
      READ (10) ZZZ                                                     06080
      REWIND 10                                                         06090
      GOTO 10                                                           06100
402   VANGLE=TEMP(1)/RAD                                                06110
      VCOS=COS(VANGLE)                                                  06120
      VSPAN=TEMP(2)                                                     06130
      VCHORD=TEMP(3)                                                    06140
      VXO=TEMP(4)                                                       06150
      VY=TEMP(5)                                                        06160
      VZO=TEMP(6)                                                       06170
      VTC=TEMP(7)                                                       06180
      VAREA=VCHORD*VSPAN                                                06190
      GOTO 10                                                           06200
                                                                        06210
C     STERNSEAL                                                         06220
500   CONTINUE                                                          06230
      XSSI=TEMP(1)                                                      06240
      ZSSI=TEMP(2)                                                      06250
      ALEAK=TEMP(3)                                                     06260
      CFSS=TEMP(4)                                                      06270
      THSSI=TEMP(5)                                                     06280
      DPSS=TEMP(6)                                                      06290
      XLF=TEMP(7)                                                       06300
      SINTH=SIN(THSSI/RAD)                                              06310
      COSTH=COS(THSSI/RAD)                                              06320
      ELMAXS=XLF*COSTH                                                  06330
      GO TO 10                                                          06340
                                                                        06350
C     BCWSEAL                                                           06360
600   CONTINUE                                                          06370
      XBSI=TEMP(1)                                                      06380
      CFBS=TEMP(2)                                                      06390
      DPBS=TEMP(3)                                                      06400
      ELMAXB=TEMP(4)                                                    06410
      GOTO 10                                                           06420
                                                                        06430
C     PLENUM                                                            06440
```

```
700   CONTINUE                                                          06450
      GO TO (705,710),IOPT                                              06460
 705  CONTINUE                                                          06470
      XLBW=TEMP(1)                                                      06480
      XBBW=TEMP(2)                                                      06490
      WIDTH=TEMP(4)                                                     06500
      XL=TEMP(5)                                                        06510
      XCPO=TEMP(6)                                                      06520
      BUBHGT=TEMP(7)                                                    06530
      ABW=XBBW*XLBW                                                     06540
      AB=WIDTH*XL                                                       06550
      VOLNOM=(ABW+AB)*BUBHGT/2.                                         06560
      GOTO 10                                                           06570
 710  CONTINUE                                                          06580
      FNCRIT=TEMP(1)                                                    06590
      GO TO 10                                                          06600
                                                                        06610
C     PROPULSION                                                        06620
800   CONTINUE                                                          06630
      GO TO (805,810),IOPT                                              06640
 805  CONTINUE                                                          06650
      XPO=TEMP(1)                                                       06660
      YPO=TEMP(2)                                                       06670
      ZPO=TEMP(3)                                                       06680
      THRSTO=TEMP(4)                                                    06690
      STHRST=TEMP(5)                                                    06700
      GO TO 10                                                          06710
 810  TOUT=TEMP(1)                                                      06720
      IF(TOUT.LT.STIME) TOUT=STIME                                      06730
      GOTO 10                                                           06740
                                                                        06750
C     RUDDER                                                            06760
900   CONTINUE                                                          06770
      GO TO (905,910,915),IOPT                                          06780
  905 XRO = TEMP(1)                                                     06790
      YR=TEMP(2)                                                        06800
      ZRO = TEMP(3)                                                     06810
      RSPAN=TEMP(4)                                                     06820
      RASPR=TEMP(5)                                                     06830
      RAREA=TEMP(6)                                                     06840
      RCLB=2.*PI*RASPR/(RASPR+3.)                                       06850
      RTC=TEMP(7)                                                       06860
      GO TO 10                                                          06870
 910  DLRDO=TEMP(1)                                                     06880
      RDNO=TEMP(2)                                                      06890
      RMAXO=TEMP(3)                                                     06900
      RRATO=TEMP(4)                                                     06910
      RREVO=TEMP(5)                                                     06920
```

```
      RRDMAX=TEMP(6)                                                    06930
      RRDRAT=TEMP(7)                                                    06940
      GO TO 10                                                          06950
  915 CONTINUE                                                          06960
      GOTO 10                                                           06970
C     AERODYNAMICS                                                      06980
 1000 CONTINUE                                                          06990
      XLAERO=TEMP(1)                                                    07000
      BEAM=TEMP(2)                                                      07010
      RHOA=.5*RHOINF*XLAERO*BEAM                                        07020
      GOTO 10                                                           07030
C     WAVES                                                             07040
 1100 CONTINUE                                                          07050
      IWAVSW=IOPT                                                       07060
      NWAVE=TEMP(1)                                                     07070
      IF(NWAVE .EQ. 0) GOTO 10                                          07080
      IF(NWAVE .GT. 10) GOTO 70                                         07090
      BETAD=TEMP(2)                                                     07100
      BETA=BETAD/RAD                                                    07110
      COSBET=COS(BETA)                                                  07120
      SINBET=SIN(BETA)                                                  07130
      TC = 1.0                                                          07140
      GOTO ( 1104,1106) ,IWAVSW                                         07150
 1104 DO 1105 I=1,NWAVE                                                 07160
 1105 READ(5,1190) OMEGA(I),AW(I)                                       07170
      GOTO 10                                                           07180
 1106 DO 1107 I=1,NWAVE                                                 07190
 1107 READ (5,1190) WAVLEN(I) ,AW(I)                                    07200
      GOTO 10                                                           07210
C     INITIAL CONDITIONS                                                07220
 1200 CONTINUE                                                          07230
      UO = TEMP(1)                                                      07240
      THETO = TEMP(2)                                                   07250
      DSO = TEMP(3)                                                     07260
      DELPI=TEMP(4)                                                     07270
      GO TO 10                                                          07280
C     INPUT COMPLETED. 1) PRINT ALL INPUT                               07290
 1300 CONTINUE                                                          07300
      WRITE (6,2000) TITLC                                              07310
      WRITE (6,2001) STIME,FTIME,DELO,TPRINO,DELPNT                     07320
      WRITE (6,2002) IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IRUD,07330
     1 IPROP,IAEROD,IRHS                                                07340
      WRITE(6,2021) I3DOF,ISRGE,ITRIM                                   07350
      WRITE (6,2003) NEQS, (TOL(J),J=1,NEQS)                            07360
                                                                        07370
                                                                        07380
```

```
      WRITE (6,219) WEIGHT,XS,ZS,AIXX,AIYY,AIZZ,AIXZ                    07390
      WRITE(6,217)A,AIMAX                                               07400
      WRITE (6,2018) NSTA                                               07410
      WRITE (6,490) YSW,XLSW,CFSW,CDSW,VANGLE,VSPAN,VCHORD,VXO,VY,VZO,  07420
     1 AVBMSW,VTC                                                       07430
      WRITE (6,491) NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB     07440
      IF (IMM.GT.0)  WRITE(6,1549)    (XMO(J),J=1,IMNX)                 07450
      WRITE (6,1519) IMM,IMNX,IMNY,IBMFIL,BTIME,INT                     07460
      IF (IMN.GT.0)  WRITE(6,1559) (YMI(J),J=1,IMNY)                    07470
      WRITE (6,2010) XLBW,XBBW                                          07480
      WRITE (6,2011) XL,WIDTH,XCPO,VOLNOM,BUBHGT                        07490
      WRITE (6,2020) DELPI                                              07500
      WRITE(6,2009) FNCRIT,XLTOT                                        07510
      WRITE (6,2028) ENBFAN,BRPM,ENMFAN,EMRPM,ENSFAN,SRPM               07520
      WRITE (6,2013) XRO,YR,ZRO,RONO,RMAXO,RRATC,RREVO,DLRDO            07530
     1  ,RSPAN,RASPR,RAREA,RCLB,RTC                                     07540
      THRUST =THRSTO*2.                                                 07550
      WRITE (6,2012)        XPO,YPO,ZPO,TOUT,THRUST,STHRST              07560
      WRITE (6,2027) XLAERO,BEAM                                        07570
      WRITE (6,2026) XBSI,CFBS,DPBS,ELMAXB                              07580
      WRITE (6,2025) XSSI,ZSSI,ALEAK,CFSS,THSSI,DPSS,XLF                07590
      WRITE (6,2017) UO,THETO,DSO                                       07600
                                                                        07610
C                    AND 2) INITIALIZE VARIABLES FOR CALCS.             07620
      DO 1302 I=1,40                                                    07630
 1302 VAL(I) = 0.0                                                      07640
      U = UO*1.6889                                                     07650
      XSS=-(XS-XSSI)                                                    07660
      ZSS=ZS-ZSSI                                                       07670
      THETA = THETO/RAD                                                 07680
      THEQL=THETA                                                       07690
      DS = DSO/12.                                                      07700
      Z=-ZS+DS                                                          07710
      ZEQUIL=Z                                                          07720
      PHIMAX=0.                                                         07730
      TROLL=0.                                                          07740
      DELRUD=DLRDO/RAD                                                  07750
      TANRUD=TAN(DELRUD)                                                07760
      COSRUD =COS(DELRUD)                                               07770
      RUDON=RONO                                                        07780
      RUDMAX=RMAXO                                                      07790
      RUDRAT=RRATO                                                      07800
      RUDREV=RREVO                                                      07810
      IF ( RUDRAT.NE.0.0 )  RUDOFF = RUDON+RUDMAX/RUDRAT                07820
      IF (RUDREV .LT. RUDOFF) RUDREV=RUDOFF                             07830
      IRDS=0                                                            07840
      TL=0.0                                                            07850
C     WAVE PARAMETERS TABLE                                             07860
```

```
      IF(NWAVE .EQ.0) GOTO 1321                                          07870
      AMPTC=1.30287                                                      07880
      GOTO(1310,1315),IWAVSW                                             07890
1310  DO 1311 I=1,NWAVE                                                  07900
1311  WAVLEN(I)=2.*PI*G/(OMEGA(I)*OMEGA(I))                              07910
      GOTO 1317                                                          07920
1315  DO 1316 I=1,NWAVE                                                  07930
1316  OMEGA(I)=SQRT(2.*PI*G/WAVLEN(I))                                   07940
1317  CONTINUE                                                           07950
                                                                         07960
C     CALCULATE INITIAL FREQUENCIES OF ENCOUNTER                         07970
      DO 1318 I=1,NWAVE                                                  07980
      WAVSLP(I) = 360.0*AW(I)/WAVLEN(I)                                  07990
      OMEGAE(I) =2.*PI*(SQRT(G*WAVLEN(I)/(2.*PI))-U*COSBET)/WAVLEN(I)    08000
      ENCPER(I) = 2.0*PI/OMEGAE(I)                                       08010
1318  CONTINUE                                                           08020
      WRITE (6,1191) NWAVE,BETAD,(OMEGA(I),OMEGAE(I),WAVLEN(I),AW(I),    08030
     1               WAVSLP(I),ENCPER(I),I=1,NWAVE)                      08040
      GOTO 1322                                                          08050
1321  WRITE (6,1192)                                                     08060
1322  CONTINUE                                                           08070
      DO 1303 I=1,4                                                      08080
      DO 1303 N=1,11                                                     08090
1303  ETA(I,N) = 0.0                                                     08100
      DVOLW = 0.0                                                        08110
      FXWAV = 0.0                                                        08120
      FYWAV = 0.0                                                        08130
      FZWAV = 0.0                                                        08140
      FKWAV = 0.0                                                        08150
      FMWAV = 0.0                                                        08160
      FNWAV = 0.0                                                        08170
      ZBAR=Z                                                             08180
      PHIBAR=PHI                                                         08190
      THEBAR=THETA                                                       08200
      TIME=STIME                                                         08210
      DELT = DELO                                                        08220
      TPRINT=TPRINO-DELPNT                                               08230
      PWVCON=4.*WEIGHT/(RHO*G*XLBW)                                      08240
      FNCON=SQRT(XLBW*G)                                                 08250
      VX=VXO-XS                                                          08260
      VZ = ZS-VZO                                                        08270
      XP=XPO-XS                                                          08280
      XR = XRO-XS                                                        08290
      YP=YPO                                                             08300
      ZP=ZS-ZPO                                                          08310
      ZR = ZS-ZRO                                                        08320
      IF (IMM.EQ. 0) GO TO 1305                                          08330
      DO 1304 J=1,IMNX                                                   08340
```

```
 1304 XMI(J) = XMO(J) - XS                                                      08350
 1305 CONTINUE                                                                  08360
      XCP = XCPO-XS                                                             08370
      ZCP = ZS-BUBHGT                                                           08380
      XBS=XBSI-XS                                                               08390
      N=NSTA(3)                                                                 08400
      ANG=-PI/2.                                                                08410
      DANG=PI/(N-1)                                                             08420
      RBS=XBBW/2.                                                               08430
      DSBS=RBS*DANG                                                             08440
      DO 1364 J=1,N                                                             08450
      XX(3,J)=XBS+RBS*COS(ANG)                                                  08460
      YY(3,J)=RBS*SIN(ANG)                                                      08470
      ANG=ANG+DANG                                                              08480
 1364 CONTINUE                                                                  08490
      N=N-1                                                                     08500
      DO 1367 J=1,N                                                             08510
      YAVGB(J)=(YY(3,J+1)+YY(3,J))/2.                                           08520
      DELYBS(J)=YY(3,J+1)-YY(3,J)                                               08530
1367  CONTINUE                                                                  08540
      N=NSTA(4)                                                                 08550
      DELYSS=XBBW/(N-1)                                                         08560
      DO 1365 J=1,N                                                             08570
      XX(4,J)=-XS                                                               08580
      YY(4,J)=-.5*XBBW+(J-1)*DELYSS                                             08590
 1365 CONTINUE                                                                  08600
      N=N-1                                                                     08610
      DO 1368 J=1,N                                                             08620
      YAVGS(J)=(YY(4,J+1)+YY(4,J))/2.                                           08630
 1368 CONTINUE                                                                  08640
      XBOW=XLTOT-XS                                                             08650
      N=NSTA(1)                                                                 08660
      DELX=XBSI/(N-1)                                                           08670
      DO 1309 J=1,2                                                             08680
      DO 1309 I=1,N                                                             08690
      XX(J,I)=(I-1)*DELX-XS                                                     08700
1309  YY(J,I)= YSW*(2*J-3)                                                      08710
      WRITE(6,1366) ((XX(J,N),N=1,11),(YY(J,N),N=1,11),J=1,4)                   08720
 1366 FORMAT (//17H XX AND YY ARRAYS /14H PORT SIDEWALL /2(11F10.2/),           08730
     1 15H STBD. SIDEWALL /2(11F10.2/),9H BOW SEAL /2(11F10.2/),                08740
     2 11H STERN SEAL /2(11F10.2/))                                             08750
      N=NSTA(1)-1                                                               08760
      DO 1308 I=1,N                                                             08770
1308  XAVG(I)=DELX*(2*I-1)/2.-XS                                                08780
      CALL WAVES(TIME)                                                          08790
                                                                                08800
C     INITIALIZE BUBBLE PRESSURE, ABSOLUTE (PSF)                                08810
      PB=PINF+DELPI                                                             08820
```

```
      PBBAR=DELPI                                                       10/26/72
      PSS=PB+DPSS                                                       08830
      PBS=PB+DPBS                                                       08840
      AB=XL*(XBBW-(XBBW-WIDTH)*(ZS+Z)/BUBHGT)                           08850
      VOL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVOLW                               08860
      BMASS=(PB/PINF)**(1./GAM)*VOL*RHOINF                              08870
      WRITE (6,2023)                                                    08880
      RETURN                                                            08890
                                                                        08900
C     RUN TERMINATOR                                                    08910
 1400 WRITE(6,98)                                                       08920
      STOP                                                              08930
                                                                        08940
C     BENDING MOMENT                                                    08950
 1500 GO TO (1510,1520,1530,1540), IOPT                                 08960
 1510 IMM = TEMP(1)                                                     08970
      IF (IMM.GT.3)  GO TO 70                                           08980
      IMNX = TEMP(2)                                                    08990
      IF (IMNX.GT.10)  GO TO 70                                         09000
      IMNY = TEMP(3)                                                    09010
      IF (IMNY.GT.7)  GO TO 70                                          09020
      IBMFIL = TEMP(4)                                                  09030
      BTIME = TEMP(5)                                                   09040
      IF (IMM.EQ.3)  IMT = TEMP(6)                                      09050
      GO TO 10                                                          09060
 1520 DO 1521 J=1,7                                                     09070
 1521 XMO(J) = TEMP(J)                                                  09080
      IF (IMNX.LE.7)  GO TO 10                                          09090
      READ 1522, (XMO(J),J=8,IMNX)                                      09100
      GO TO 10                                                          09110
 1530 DO 1531 J=1,IMNY                                                  09120
 1531 YMI(J) = TEMP(J)                                                  09130
      GO TO 10                                                          09140
 1540 CONTINUE                                                          09150
      GO TO 10                                                          09160
                                                                        09170
C     NOT USED                                                          09180
1600  CONTINUE                                                          09190
      GO TO 10                                                          09200
                                                                        09210
C     NOT USED                                                          09220
 1700 CONTINUE                                                          09230
      GOTO 10                                                           09240
                                                                        09250
C     TITLE CARD (ALL 80 COLUMNS )                                      09260
 1800 READ  (5,2022)  TITLC                                             09270
      GO TO 10                                                          09280
                                                                        09290
```

```
C       FAN MAPS                                                        09300
1900    CONTINUE                                                        09310
        GO TO (1905,1910,1915),IOPT                                     09320
1905    CONTINUE                                                        09330
        ENBFAN=TEMP(1)                                                  09340
        BRPM=TEMP(2)                                                    09350
        NPTSB=TEMP(3)                                                   09360
        READIN=TEMP(4)                                                  09370
        IF (READIN .EQ. 0.0) GO TO 10                                   09380
        READ (5,1950) (PBFAN(J),J=1,NPTSB)                              09390
        READ (5,1950) (QBFAN(J),J=1,NPTSB)                              09400
        GO TO 10                                                        09410
1910    CONTINUE                                                        09420
        ENMFAN=TEMP(1)                                                  09430
        ENRPM=TEMP(2)                                                   09440
        NPTSM=TEMP(3)                                                   09450
        READIN=TEMP(4)                                                  09460
        IF (READIN .EQ. 0.0) GO TO 10                                   09470
        READ (5,1950) (PMFAN(J),J=1,NPTSM)                              09480
        READ (5,1950) (QMFAN(J),J=1,NPTSM)                              09490
        GO TO 10                                                        09500
1915    CONTINUE                                                        09510
        ENSFAN=TEMP(1)                                                  09520
        SRPM=TEMP(2)                                                    09530
        NPTSS=TEMP(3)                                                   09540
        READIN=TEMP(4)                                                  09550
        IF (READIN .EQ. 0.0) GO TO 10                                   09560
        READ (5,1950) (PSFAN(J),J=1,NPTSS)                              09570
        READ (5,1950) (QSFAN(J),J=1,NPTSS)                              09580
        GO TO 10                                                        09590
1950    FORMAT(8F10.0)                                                  09600
C       ERROR IN INPUT                                                  09610
   70   CONTINUE                                                        09620
        WRITE (6,79) ISYS                                               09630
        STOP                                                            09640
  79    FORMAT(34H INPUT ERROR - - - STOP - -  ISYS= ,I3)               09650
  98    FORMAT(1H1,20(/),50X,19H COMPLETED ALL RUNS )                   09660
99      FORMAT(I3,I2,7F10.0)                                            09670
 191    FORMAT (16I5)                                                   09680
 192    FORMAT (5F10.0)                                                 09690
 195    FORMAT(///10X,65HERROR IN INPUT --- DELT AND/OR DELPNT EQUALS ZERO09700
     1 --- JOB ABORTED )                                                09710
 175    FORMAT (2I2/(8F10.0))                                           2/14/73
 216    FORMAT(///10X,82HERROR IN INPUT --- INPUT INERTIA ELEMENTS LEAD TO09730
     1 ZERO DETERMINANT --- JOB ABORTED )                               09740
 217    FORMAT(22H INERTIA MATRIX, AIMAX  6E15.4/(22X,6E15.4))          09750
 219    FORMAT(30H WEIGHT, C.G., INERTIA MOMENTS 7F12.3)                 09760
 305    FORMAT ( 11F7.0 )                                               09770
```

```
  490 FORMAT(15H SIDEWALL INPUT 12(F8.3,1X))                                    09780
  491 FORMAT(26H SIDEWALL TABLE PARAMETERS 4(I4,F7.3,F7.3))                     09790
 1190  FORMAT(2F10.0)                                                          09800
 1191 FORMAT(/12HONO OF WAVES I2,10H BETA(DEG)F5.0/15H OMEGA(RAD/SEC) ,        09810
     15X,16H OMEGAE(RAD/SEC) 5X,16H WAVE LENGTH(FT) 5X,14H AMPLITUDE(FT)09820
     - 5X,16HMAX  SLOPE (DEG)5X,13HPERICD,E(SEC)/(F8.4,12X,F8.4,4F20.3))09830
 1192 FORMAT(/11HOCALM WATER)                                                  09340
 1519 FORMAT(32HOMOMENT CALC. CONTROL PARAMETERS 4I5, F8.3, I5 )               09850
 1522 FORMAT ( 5X,7F10.0)                                                      09860
 1549 FORMAT(22H MOMENT CALCS. AT X OF 11F10.3)                                09870
 1559 FORMAT(22H MOMENT CALCS. AT Y OF 11F10.3)                                09880
 2000 FORMAT(33H1SES MOTIONS AND LOADS PROGRAM - 20A4,/)                       09890
 2001 FORMAT(23H START AND FINISH TIMES 2F10.2/                                09900
     -22H INITIAL TIME INTERVAL F12.4/                                         09910
     -18H START PRINTING AT F8.2,17H IN INCREMENTS OF F8.2)                    09920
 2002 FORMAT(34H INTERMEDIATE PRINT TAGS 16I5)                                 09930
 2003 FORMAT(39H NO. OF STATE EQUATIONS, AND TOLERANCESI5/(10X,10E12.2))09940
 2010 FORMAT(34HOPLENUM, LENGTH AND WIDTH AT WATER 2F12.4)                     09950
 2011 FORMAT(34H PLENUM, LENGTH AND WIDTH AT HULL  2F12.4/                     09960
     -       35H PLENUM, CENTER OF PRESSURE AT HULL F12.4/                     09970
     -29H PLENUM, NOMINAL VOLUME F12.1,10X, 6HHEIGHT F12.4)                    09980
 2009 FORMAT(23HOCRITICAL FROUDE NUMBER F15.4,5X,19H TOTAL CRAFT LENGTH 09990
     1       F15.4)                                                           10000
 2012 FORMAT(/33H PROPULSION, X, Y, Z COORDINATES  3F12.4/                     10010
     -        33H PROPULSION, TOUT, THRUST, STHRST  3F12.2/)                   10020
 2013 FORMAT(/28HORUDDER, X, Y, Z COORDINATES  3F12.4/                         10030
     -        41H RUDDER, ON, MAX, RATE, REVERSE, INITIAL  5F12.4/             10040
     -        33H RUDDER,SPAN,ASPECT,AREA,CLB,T/C  5F12.4)                     10050
 2017 FORMAT(/39HOINITIAL CONDITIONS, VELOCITY (KNOTS) = F7.2, 5X,             10060
     -        13HPITCH (DEG) = F8.3,5X,12HDRAFT (IN) = F8.2)                   10070
 2018 FORMAT( 49H NUMBER OF STATIONS, SIDEWALLS (P+S), SEALS (B+S) ,4I5)10080
 2020 FORMAT( 38H PLENUM, INITIAL PRESSURE, GAGE (PSF)  F8.2)                  10090
 2021 FORMAT(70H PROGRAM OPTION SWITCH SETTINGS (LATERAL PLANE,CONSTANT 10100
     -SPEED,TRIM)          3I5)                                              10110
 2022 FORMAT (20A4 )                                                           10120
 2023 FORMAT ( 1H1 )                                                           10130
 2025 FORMAT( 16H STERNSEAL INPUT  7F12.4 )                                    10140
 2026 FORMAT( 16H BOWSEAL INPUT    7F12.4 )                                    10150
 2027 FORMAT( 19HOAERODYNAMICS INPUT  7F12.4)                                  10160
 2028 FORMAT( 33HOFANS, NO. + RPM, BOW,MAIN,STERN  3(F10.0,F10.1))             10170
      END                                                                      10180


      SUBROUTINE INTGRL (TIME)                                                10190
      INTEGER ON                                                              10200
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY10210
      COMMON /EQNCO/ NEQS,TOL(20),JQQ                                          6/4/73
      COMMON /KSWTCH/ ITHRST                                                  10230
```

```
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,    10240
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO          10250
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                       10260
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,    10270
     -IRUD,IPROP,IAEROD,IRHS                                              10280
      COMMON /STABLE/ S(4),ISTAB                                          10290
      COMMON / VALOLD / YOLD(20)                                          10300
      COMMON /VARBLE/ VAL(40)                                             10310
                                                                          10320
      EQUIVALENCE (VAL(1),X),(VAL(2),Y(1))                                10330
      DIMENSION Y(20),ERROR(20)                                           10340
      REAL K1(20),K2(20),K3(20),K4(20),K5(20)                             10350
      DATA IPASS/0/                                                       10360
                                                                          10370
    1 IF((TIME+DELT).LE.TPRINT) GO TO 12                                  10380
      DEL=DELT                                                            10390
      DELT=TPRINT-TIME                                                    10400
      IPASS=1                                                             10410
   12 X=TIME                                                              10420
      DO 2 J=1,NEQS                                                       10430
      Y(J)=YOLD(J)                                                        10440
    2 CONTINUE                                                            10450
      ITHRST=1                                                            10460
      CALL RHS(K1)                                                        10470
      ITHRST=2                                                            10480
      IMT = 0                                                             10490
      IF (IACCEL.NE. ON) GO TO 14                                         10500
      ACCLAT = (K1(2)+Y(1)*Y(6))/G                                        10510
      WRITE  (6,101)  ACCLAT , DELT                                       10520
   14 ON=2                                                                10530
   15 H=DELT/3.                                                           10540
      X=TIME+H                                                            10550
      DO 3 J=1,NEQS                                                       10560
    3 Y(J)=YOLD(J)+H*K1(J)                                                10570
      CALL RHS(K2)                                                        10580
      DO 4 J=1,NEQS                                                       10590
    4 Y(J)=YOLD(J)+.5*H*(K1(J)+K2(J))                                     10600
      CALL RHS(K3)                                                        10610
      X=TIME+.5*DELT                                                      10620
      DO 5 J=1,NEQS                                                       10630
    5 Y(J)=YOLD(J)+.375*H*(K1(J)+3.*K3(J))                                10640
      CALL RHS(K4)                                                        10650
      X=TIME+DELT                                                         10660
      DO 6 J=1,NEQS                                                       10670
    6 Y(J)=YOLD(J)+.5*H*(3.*K1(J)-9.*K3(J)+12.*K4(J))                     10680
      CALL RHS(K5)                                                        10690
      IF (JQQ.EQ.1) GO TO 7                                               5/4/73
      DO 7 J=1,NEQS                                                       10700
```

```
      ERROR(J)=(K1(J)-4.5*K3(J)+4.*K4(J)-.5*K5(J))*H/5.0                    10710
      IF(ABS(ERROR(J)).GT.TOL(J)) GO TO 11                                  10720
    7 CONTINUE                                                              10730
      DO 105 J=1,NEQS                                                       10740
      Y(J)=YOLD(J)+.5*H*(K1(J)+4.*K4(J)+K5(J))                              10750
  105 YOLD(J)=Y(J)                                                          10760
      TIME=TIME+DELT                                                        10770
      IF (IPASS.EQ.1) GO TO 8                                               10780
      IF (JQQ.EQ.1) GO TO 10                                                5/6/73
      DO 75 J=1,NEQS                                                        10790
      IF(ABS(ERROR(J)).GT.TOL(J)/16.) GO TO 10                              10800
   75 CONTINUE                                                              10810
      DELT=2.*DELT                                                          10820
      IF (DELT.GT.DELPNT) DELT=DELPNT                                       10830
   10 RETURN                                                                10840
    8 DELT=DEL                                                              10850
      IPASS=0                                                               10860
      GO TO 10                                                              10870
   11 DELT=DELT/2.                                                          10880
      IF (DELT.LT. 1.E-6 )  GO TO 25                                        10890
                        WRITE (6,666) TIME,DELT,J,ERROR(J),TOL(J)           10900
      IPASS = 0                                                             10910
      GO TO 15                                                              10920
   25 WRITE ( 6,150 )                                                       10930
      WRITE (6,100) TIME,DELT,(K1(J),J=1,NEQS),VAL                          10940
      STOP                                                                  10950
  100 FORMAT(/10X,23HINTGRL TIME,DELT,K1,VAL /2E15.4/2(5E15.4/),5(8E15.4    10960
     1))                                                                    10970
  101 FORMAT(1H0,9X,33HTOTAL LATERAL ACCELERATION (G) =    F12.4,           10980
     112X,5HDT =  E15.4)                                                    10990
  150 FORMAT(1H1,10X,44HDELTA TIME LESS THAN 1.0E-6 -  -  JOB STOPS )       11000
  666 FORMAT(/10X,5HINT-J 2E30.5,I5,2E20.5)                                 11010
      END                                                                   11020

      SUBROUTINE PROP                                                       11030
      INTEGER ON                                                            11040
      COMMON /CONST/ PI,RAD,UO                                              11050
      COMMON /FPROP/ FX,FY,FZ,FK,FM,FN                                      11060
      COMMON / ENGINE / TOUT,THRUST,THRSTO,STHRST,XP,YP,ZP                  11070
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,      11080
     -IRUD,IPROP,IAEROD,IRHS                                                11090
      COMMON /VARBLE/ VAL(40)                                               11100
                                                                            11110
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),           11120
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),         11130
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),    11140
     3(VAL(24),PB)                                                          11150
```

```
C       CHECK ENGINE OUT CONDITION (PORT)                                       11160
        NPROP = 2                                                               11170
        IF (TIME.GE.TCUT)  NPROP = 1                                            11190
        FX = 0.0                                                                11200
        FY = 0.0                                                                11210
        FZ = 0.0                                                                11220
        FK = 0.0                                                                11230
        FM = 0.0                                                                11240
        FN = 0.0                                                                11250
                                                                                11260
        DO 10 I=1,NPROP                                                         11270
        PJ = 2*I-3                                                              11280
        FX = FX+THRSTO                                                          11290
        FY = FY+STHRST*PJ                                                       11300
        FZ = FZ-THRSTO*THETA                                                    11310
        FK = FK+(THRSTO*THETA*YP-STHRST*ZP)*PJ                                  11320
        FM = FM+THRSTO*ZP                                                       11330
        FN = FN+(STHRST*XP+THRSTO*YP)*PJ                                        11340
   10 CONTINUE                                                                  11350
    2   IF (IPROP.NE.ON) RETURN                                                 11360
                        WRITE(6,123)                                            11370
       1FX,FY,FZ,FK,FM,FN                                                       11380
  123 FORMAT(/10X,22HPROP FX,FY,FZ,FK,FM,FN  /6E15.4)                           11390
        RETURN                                                                  11400
        END                                                                     11410


        SUBROUTINE RHS(VALUE)                                                   11420
******NOTE ALL LINES BEGINNING****SES/BH8*****
        INTEGER ON                                                              11430
                                                                                11440
        COMMON /AIR/ PINF,RHOINF,GAM                                            11450
        COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY      11460
        COMMON /COLUMN/ IVERT,ILATRL                                            11470
        COMMON /CONST/ PI,RAD,UO                                                11480
        COMMON /CNTRL/CONTW,CONTQ,CONTTH,QMULT,LOUVER,ACONTZ,ACONTW,ZEQUIL      11490
       1 ,THEQL,ACBASE                                                          11500
        COMMON / ENGINE / TOUT,THRUST,THRSTO,STHRST,XP,YP,ZP                    11510
        COMMON /EQNCO/ NEQS,TOL(20),JQQ                                         11/4/73
        COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,         11520
       1 ENSFAN,BRPM,MRPM,SRPM,NPTSB,NPTSM,NPTSS                                11530
       2 ,PBFAN(25),PMFAN(25),PSFAN(25)                                         11540
        COMMON /FAERO/ FXAED,FYAED,FZAED,FKAED,FMAED,FNAED                      11550
        COMMON /FORBS/FXBS,FYBS,FZBS,FKBS,FMBS,FNBS,QLBS                        11560
        COMMON /FORSS/FXSS,FYSS,FZSS,FKSS,FMSS,FNSS,QLSS,FMS                    11570
        COMMON /FPROP/ FXP,FYP,FZP,FKP,FMP,FNP                                  11580
        COMMON / FROUDE / FN,FNCRIT                                             11590
        COMMON /FRUD/ FXRUD,FYRUD,FZRUD,FKRUD,FMRUD,FNRUD                       11600
```

```
      COMMON/GBOW/ XBOW                                                 11610
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM     11620
     1,DELS(4,10),XCP,ZCP                                               11630
      COMMON /GEOMBS/DETABX(11),DETABT(11),ARM1B(10),ARM2B(10)          11640
     1 ,DFBS(10),TSKIB(10)                                              11650
      COMMON /GEOMSS/DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10) 11660
     1 ,ARM2S(10)                                                       11670
      COMMON /KSWTCH/ ITHRST                                            11680
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,  11690
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO       11700
      COMMON /MATRIX/ A(6,6)                                            11710
      COMMON /MSIDW/ DF(2,10),DSWAV(2,10),FXH(2),FYH(2),FZH(2),FMH(2),  11720
     1               FNH(2),VFY(2),VFZ(2),FXV                           11730
      COMMON /MWAVE/ FXW(2),FYW(2),FZW(2),FKW(2),FMW(2),FNW(2)          11740
      COMMON /OPTION/ I3DOF,ISRGE,ITRIM                                 11750
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT                               11760
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                     11770
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,  11780
     -IRUD,IPROP,IAEROD,IRHS                                            11790
      COMMON /PWAVE/ FNCON,PWVCON                                       11800
      COMMON /RUDDR/ DELRUD,RUDON,RUDOFF,RUDRAT,CCSRUD,XR,YR,ZR,TANRUD  11810
     1  ,RUDREV,IRDS,TL,RSPAN,RAREA,RASPR,RCLB,RTC                      11820
     2  ,RUDMAX,RRDRAT,RRDMAX                                           2/24/73
      COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSW11830
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC      11840
      COMMON /SOFTBS/DSBS,CFBS,PBS,DPBS,YAVGB(10),DELYBS(10),ELMAXB     11850
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS           11860
     1 ,ELMAXS,YAVGS(10)                                                11870
      COMMON / VALOLD / YOLD(20)                                        11880
      COMMON /VARBLE/ VAL(40)                                           11890
      COMMON /WAVE/ ETA(4,11),AW(10),CMEGA(10),DVCLW,NWAVE,BETA,        11900
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                 11910
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR          10/26/72
                                                                        11930
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),       11940
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     11950
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),11960
     3(VAL(24),PB)                                                      11970
      EQUIVALENCE (VAL(18),FANPWR)                                      11980
                                                                        11990
      DATA NOTIN /0/                                                    12000
      DIMENSION ACCEL(3),ANGACL(3)                                      12010
      DIMENSION GF(6),VALUE(20)                                         12020
      DO 5 J=1,20                                                       12030
    5 VALUE(J)=0.0                                                      12040
                                                                        12050
      AB=XL*(XBBW-(XBBW-WIDTH)*(ZS+Z)/BUBHGT)                           12060
      VOL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVCLW                               12070
```

```
      PB=PINF*(BMASS/(VOL*RHOINF))**GAM                                    12080
      PBAR=PB-PINF                                                         12090
      PBS=1.250*PBAR+PINF                                                  12100
      PSS=1.25*PBAR+PINF                                                   12110
      ABPB=PBAR*AB                                                         12120
                                                                           12130
C     CALCULATION OF BUBBLE WAVE MAKING DRAG                               12140
      FN=U/FNCON                                                           12150
      CF=.37/(FN**1.5655981)                                               12160
      FXPWAV=-PWVCON*PBBAR*CF                                              10/26/72
      FLOW=SQRT(2.*ABS(PBAR)/RHOINF)*SIGN(1.,PBAR)                         12180
      QLSW=CFSW*ALSW*FLOW                                                  12190
                                                                           12200
      CALL BOWSL                                                           12210
      CALL STNSL                                                           12220
                                                                           12230
      GF(1)=FXBS+FXSS+FXSW+FXRUD+FXP+FXWAV+FXAED          +FXPWAV          12240
      IF (ITHRST.NE.ITRIM) GO TO 11                                        12250
                                                                           12260
      THRSTO=THRSTO-GF(1)/2.                                               12270
      THRUST=THRSTO*2.                                                     12280
      IF(ITRIM.EQ.ON)                                                      12290
     1WRITE(6,76) FXBS,FXSS,FXSW,FXRUD,FXP,FXWAV,FXAED,ABPB,FXPWAV        12300
     1 ,THRUST                                                             12310
   76 FORMAT(//10X,3HRHS                                                   12320
     1/42H FX COMPONENTS (AS LISTED IN RHS +THRUST)  /10E13.5)             12330
      GF(1) = 0.0                                                          12340
   11 CONTINUE                                                             12350
      GF(2)=-R*U*AM+FYBS+FYSS+FYSW+FYRUD+FYP+FYWAV+FYAED                   12360
      GF(3)=WEIGHT-ABPB          +FZBS+FZSS+FZSW+FZRUD+FZP+FZWAV+FZAED     12370
      GF(4)=FKBS+FKSS+FKSW+FKRUD+FKP+FKWAV+FKAED +ABPB*PHI*(-Z)            12380
      FKBUB=ABPB*PHI*(-Z)                                                  2/5/73
      GF(5)=FMBS+FMSS+FMSW+FMRUD+FMP+FMWAV+FMAED +ABPB*(XCP-THETA*Z )      12390
     -      +FXPWAV*ZS                                                     12400
      GF(6)=FNBS+FNSS+FNSW+FNRUD+FNP+FNWAV+FNAED                           12410
      IF( I3DOF .NE. 1) GO TO 100                                          12420
      GF(3)=0.0                                                            12430
      GF(5)=0.0                                                            12440
  100 CONTINUE                                                             12450
      DO 1 I=1,6                                                           12460
      VALUE(I)=0.0                                                         12470
      DO 1 J=1,6                                                           12480
      VALUE(I)=VALUE(I)+A(I,J)*GF(J)                                       12490
    1 CONTINUE                                                             12500
                                                                           12510
      VALUE(7)=P                                                           12520
      VALUE(8)=Q                                                           12530
      VALUE(9)=W                                                           12540
```

```
      IF (I3DOF .EQ. 1 ) GO TO 325                                          12550
C     BUBBLE PRESSURE EQUATION                                              12560
      QOUT=QLBS+QLSS+QLSW                                                   12570
      CALL FAN                                                              12580
      QCNTRL=0.0                                                            12590
      VALUE(10)=RHOINF*(QIN-QOUT-QCNTRL)                                    12600
      GO TO 236                                                             12610
 325  CONTINUE                                                              12620
      VALUE(10)=0.0                                                         12630
 236  CONTINUE                                                              12640
                                                                            12650
C     WRITE DATA FILE FOR MOMENT AND SHEAR CALCS., IF REQUIRED              12660
      IF ( IMT.NE.1 )  GO TO 111                                            12670
      NBS = NSTA(3)-1                                                       12680
      NSS = NSTA(4)-1                                                       12690
      NSSL = NSS/2+1                                                        12700
                  WRITE (IBMFIL)  (VAL(I),I=1,24),ZBAR,PHIBAR,THEBAR,       12710
     -                FXW,FYW,FZW,FKW,FMW,FNW, (VALUE(I),I=1,10),           12720
     -                DF,DSWAV,FXH,FYH,FZH,FMH,FNH,VFY,VFZ,FXV ,            12730
     -                FXRUD,FYRUD,FXP,FYP,FZP,  FZSS,FKSS,FMSS,FXBS,FZBS,   12740
     -                FXAED,FYAED,FZAED,FMAED,FNAED,FXPWAV,FXSS,FKBS,FMBS   12750
     X ,FNBS,FNSS ,(TSKIS(I),DFSS(I),I=NSSL,NSS)                            12760
     Y             ,(TSKIB(I),DFBS(I),ARM1B(I),ARM2B(I),I=1,NBS)            12770
 111  CONTINUE                                                              12780
                                                                            12790
C     CONSTANT LONGITUDINAL VELOCITY ( U )                                  12800
      IF (ISRGE .EQ.1) VALUE(1)=0.0                                         12810
                                                                            12820
      IF (ON.NE.1) RETURN                                                   12830
      DO 2 I=1,3                                                            12840
      ACCEL(I)=VALUE(I)/G                                                   12850
      ANGACL(I)=VALUE(I+3)*RAD                                              12860
  2   CONTINUE                                                              12870
      BCWACC=ACCEL(3)-XBOW*VALUE(5)/G                                       12880
      STNACC=ACCEL(3)+XS*VALUE(5)/G                                         12890
      IF (IVERT.NE.ON) GO TO 10                                             12900
      ZD=Z+ZS                                                               12910
      THETAR=THETA*RAD                                                      12920
      WRITE(1) TIME,VAL(16),ZD,THERAR,PBAR,(GF(I),I=1,6)                    12930
*****WRITE(1) TIME,ZD,THETAR,PBAR,GF(4),FKBS,FKSS,FKSW,FKRUD,FKP,FKWAV,    2/5/73
*****1FKAED,FKBUB                                                          2/5/73
 10   IF (ILATRL.NE.ON) GO TO 15                                            12950
      PDEG=P*RAD                                                            19/4/73
      QDEG=Q*RAD                                                            19/4/73
      DPSI=PSI*RAD                                                          19/4/73
      RDEG=R*RAD                                                            12960
      BETAS=-V/U*RAD                                                        12970
```

```
      ACCLAT=(VALUE(2)+U*R)/G                                                  12980
      DPHI=PHI*RAD                                                             12990
      IF(R.EQ.0.0) GO TO 115                                                   13000
      TRADUS=U/R                                                               13010
      GO TO 20                                                                 13020
  115 TRADUS=1.E8                                                              13030
   20 WRITE(2) (VAL(I),I=1,4),PDEG,QDEG,RDEG,DPHI,BETAS,X,Y,Z,DPSI             19/4/73
   15 IF (IRHS .NE. ON) RETURN                                                 13050
      WRITE(6,200) PBAR,FANPWR,QIN,QLBS,QLSW,QLSS                              13060
      WRITE(6,215) AB,VOL                                                      13070
                   WRITE(6,213) VALUE,VAL                                      13080
      WRITE(6,150) GF,ACCEL,ANGACL                                             13090
      WRITE(6,175)BOWACC,STNACC                                                13100
  200 FORMAT(//10X,3HRHS                                                       13110
     120H GAGE PRESS. (PSF) = F7.2,5X,21HFAN POWER REQD (HP) =  F8.2,          13120
     25X,27HFAN FLOW RATE (CU FT/SEC) =  F9.2,                                 13130
     3//31H LEAKAGE FLOW RATES (CU FT/SEC)  //11H BOW SEAL = F9.2,             13140
     411H SIDEWALL = F9.2,13H STERN SEAL = F9.2)                               13150
  215 FORMAT(/13H PLENUM AREA= F9.2,10X,14HPLENUM VOLUME= F10.2)               13160
  213 FORMAT(//12H VALUE ARRAY 2(/10E13.4)/10H VAL ARRAY 4(/10E13.4))          13170
  150 FORMAT(/10X,24HTOTAL FORCES AND MOMENTS 6E12.4/10X,24HACCELERATION13180
     -S G,DEG/SEC2 6E12.4)                                                     13190
  175 FORMAT(/10X,16HBOW ACCEL. (G) = E12.4,21H   STERN ACCEL. (G) = E1213200
     -.4)                                                                      13210
      RETURN                                                                   13220
      END                                                                      13230


      SUBROUTINE RUDDER                                                        13240
      INTEGER ON                                                               13250
      COMMON /CONST/ PI,RAD,U0                                                 13260
      COMMON /FRUD/ FX,FY,FZ,FK,FM,FN                                          13270
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,        13280
     -               AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO               13290
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,         13300
     -IRUD,IPROP,IAEROD,IRHS                                                   13310
      COMMON /RUDDR/ DELRUD,RUDON,RUDCFF,RUDRAT,CCSRUD,XR,YR,ZR,TANRUD         13320
     1   ,RUDREV,IRDS,TL,RSPAN,RAREA,RASPR,RCLB,RTC                            13330
     2   ,RUDMAX,RRDRAT,RRDMAX                                                 2/24/73
      COMMON /VARBLE/ VAL(40)                                                  13340
                                                                               13350
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),              13360
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),            13370
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),       13380
     3(VAL(24),PB)                                                             13390
      EQUIVALENCE (VAL(18),FANPWR)                                             13400
      DATA ENU /1.28E-5/                                                       13410
                                                                               13420
```

```
C       CALCULATE PROGRAMMED RUDDER DEFLECTION                                  13430
        IF(RUDREV .EQ. 0.) GOTO 10                                              13440
        IF( IRDS .EQ. 1) GOTO 10                                                13450
        IF (TIME .LT. RUDREV) GOTO 10                                           13460
        IRDS=1                                                                  13470
        TL=TIME                                                                 13480
        RUDON=RUDREV
        RUDRAT=-RRDRAT
        RUDOFF=RUDREV-(RUDMAX-RRDMAX)/RUDRAT
        RUDMAX=RRDMAX                                                           2/23/73
10      CONTINUE                                                                13510
        IF (TIME.LE.RUDON.OR.TIME.GE.RUDOFF) GO TO 8                            13520
        DELROL=DELRUD                                                           13530
        DELRUD=DELROL +(TIME-TL)*RUDRAT/RAD                                     13540
      8 CONTINUE                                                                13560
        IF (TIME.GE.RUDOFF ) DELRUD=RUDMAX/RAD                                  2/23/73
        TL=TIME                                                                 13550
C       SIDE FORCE ON RUDDER                                                    13570
        DSR=Z+ZS-XR*THETA                                                       13580
        ENDFAC=(1.+DSR/(DSR+RSPAN))                                             13590
        VH=V+XR*P-ZR*P                                                          13600
        QQ=HRHO*U*U*RAREA                                                       13610
        EFFANG=DELRUD-ENDFAC*VH/U                                               13620
        FY=2.*QQ*ENDFAC*RCLB*EFFANG                                             13630
                                                                                13640
C       DRAG FORCE ON RUDDER                                                    13650
        REY=U*(RAREA/RSPAN)/ENU                                                 13660
        CFR=.427/(ALOG10(REY)-.407)**2.64                                       13670
        PI8=PI/8.                                                               13680
        CD=2.*CFR+ PI8*RTC*RTC*(1.+G*RSPAN/(U*U))+RCLB*EFFANG*EFFANG            13690
        FX=-2.*CD*RAREA*HRHO*U*U                                                13700
                                                                                13710
        FZ=0.                                                                   13720
        FK=-ZR*FY                                                               13730
        FM=FX*ZR                                                                13740
        FN=XR*FY                                                                13750
        IF(IRUD.NE.CN) RETURN                                                   13760
                       WRITE(6,123)                                             13770
     1FX,FY,FZ,FK,FM,FN                                                         13780
  123 FORMAT(/10X,24HRUDDER FX,FY,FZ,FK,FM,FN /6E15.4)                          13790
        RETURN                                                                  13800
        END                                                                     13810
```

```
      SUBROUTINE SAM
      WRITE (6,10)
   10 FORMAT (1H1,'YOU HAVE CALLED A DUMMY SAM SUBROUTINE.'/
     1 11OX,'CHANGE TO BHISES TO USE THE SAM SUBROUTINE.')
      RETURN
      END


      SUBROUTINE SIDEWL                                                      19920
      INTEGER ON                                                             19930
      COMMON /AIR/ PINF,RHOINF,GAM                                           19940
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY19950
      COMMON /CONST/ PI,RAD,UO                                               19960
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM          19970
     1,DELS(4,10),XCP,ZCP                                                    19980
      COMMON /GEOMSW/ XAVG(10),DS                                            19990
      COMMON /KSWTCH/ ITHRST                                                 20000
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,      20010
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO           20020
      COMMON /MSIDW/ DF(2,10),DSWAV(2,10),FXH(2),FYH(2),FZF(2),FMH(2),       20030
     1               FNH(2),VFY(2),VFZ(2),FXV                                20040
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT                                    20050
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                          20060
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,       20070
     -IRUD,IPROP,IAEROD,IRHS                                                 20080
      COMMON /SIDE/FX   ,FY   ,FZ   ,FK   ,FM   ,FN   ,ALSW,YSW,XLSW,CFSW,CDSW20090
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC          20100
      COMMON /VARBLE/ VAL(40)                                                20110
      COMMON /WAVE/ ETA(4,11),AW(10),CMEGA(10),DVCLW,NWAVE,BETA,             20120
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                      20130
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSEET,SINBET                     20140
      COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,       20150
     1          AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),            20160
     2          AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                         20170
     3          ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                      20180
     4          AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),            20190
     5          AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                         20200
     6          ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)                       20210
     7          ,BB(36),XREF,RX                                             20220
      EQUIVALENCE                (VAL(2),U),(VAL(3),V),(VAL(4),W),          20230
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),          20240
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),20250
     3(VAL(24),PB)                                                           20260
      DIMENSION GAP(2,11),DSW(2,11)                                          20270
                                                                             20280
      DATA ENU /1.28E-5/                                                     20290
                                                                             20300
C     GAP OR WETTED DRAFT CALCULATION                                        20310
```

```
      DO 5 I=1,2                                                        20320
      DO 5 J=1,11                                                       20330
      GAP(I,J)=0.0                                                      20340
      DSW(I,J)=0.0                                                      20350
    5 CONTINUE                                                          20360
      DO 10 J=1,2                                                       20370
      N=NSTA(J)                                                         20380
      DO 10 K=1,N                                                       20390
      DD=ZS+Z+YY(J,K)*PHI-XX(1,K)*THETA+ETA(J,K)                        20400
      IF (DD.LT.BUBHGT)  GO TO 101                                      20410
      IF ( VAL(1)-TOLD .LT. DELPNT )  GO TO 101                         20420
      TOLD = VAL(1)                                                     20430
      WRITE (6,100) XX(J,K),VAL(1),DD                                   20440
  100 FORMAT(/10X,43HWATER CONTACT WITH TOP OF BUBBLE CHAMBER AT F7.2,  20450
     -14H FT.    TIME = F7.2,19H SEC.    IMMERSION= F7.2,4H FT. )      20460
  101 CONTINUE                                                          20470
      GAP(J,K)=(SIGN(1.,DD)-1.)*DD/2.                                   20480
      DSW(J,K)=(SIGN(1.,DD)+1.)*DD/2.                                   20490
   10 CONTINUE                                                          20500
                                                                        20510
C     LEAKAGE AREA                                                      20520
      ALSW=0.0                                                          20530
      DO 20 J=1,2                                                       20540
      N=NSTA(J)-1                                                       20550
      DO 20 I=1,N                                                       20560
      ALSW=ALSW+(GAP(J,I)+GAP(J,I+1))*DELX/2.                           20570
   20 CONTINUE                                                          20580
                                                                        20590
C     CROSS-FLOW DRAG ON SIDEWALLS                                      20600
      FYD=0.0                                                           20610
      FKD=0.0                                                           20620
      FND=0.0                                                           20630
      DO 15 I=1,2                                                       20640
      N=NSTA(I)-1                                                       20650
      DO 15 J=1,N                                                       20660
      DSWAV(I,J)=(DSW(I,J)+DSW(I,J+1))/2.                               20670
      VREL      =V+XAVG(J)*R-(ZS-DSWAV(I,J)/2.)*P                       20680
      DF(I,J)=-   HRHO*CDSW*VREL      *ABS(VREL      )*DELX      *DSWAV(I,J)20690
      FYD=FYD+DF(I,J)                                                   20700
      FND=FND+DF(I,J)*XAVG(J)                                           20710
   15 FKD=FKD-(ZS-DSWAV(I,J)/2.)*DF(I,J)                                20720
                                                                        20730
C     SET UP STERN LIMIT OF FORCE DETERMINATION                         20740
      XSS = -XS                                                         20750
      GO TO 16                                                          20760
                                                                        20770
      ENTRY SIDWLM                                                      20780
      XSS = XMI(IX)                                                     20790
```

```
16      IP=1.+(THETA*RAD-STH)/DTH                                       20800
        IP=MAXO(MINO(IP,NTH),1)                                         20810
        IP1=MINO(IP+1,NTH)                                              20820
        DTHETA=(IP-1)*DTH+STH                                           20830
        DIP= (THETA*RAD-DTHETA)/DTH                                     20840
                                                                        20850
C       CALC REYNOLDS NO. AND DRAG COEFF.                               20860
        REY=U*XLSW/ENU                                                  20870
        CDT=.427/(ALOG10(REY)-.407)**2.64                               20880
                                                                        20890
C       SIDEWALL FORCES, P/S                                            20900
        DO 40 J=1,2                                                     20910
        WAREA=0.0                                                       20920
        N=NSTA(J)-1                                                     20930
        NI = (XSS+XS)*N/XLSW+1.5                                        20940
        DO 21 I=NI,N                                                    20950
        ZCR1=1.                                                         20960
        IF(DSWAV(J,I).EQ. 0.0) ZCR1=0.0                                 20970
   21   WAREA=WAREA+DELX*(2.*DSWAV(J,I)+ZCR1*AVBMSW)                    20980
        FXH(J)=-   HRHC*CDT*WAREA*U*U                                   20990
                                                                        21000
        PM1=2*J-3                                                       21010
        YLSW=PM1*YSW                                                    21020
        DS= Z    +ZS+YLSW*PHI                                           21030
        DSS=DS-XSS*THETA                                                21040
        ZCR1=(SIGN(1.,DSS)+1.)/2.                                       21050
        DSS=DSS*ZCR1                                                    21060
        IDSS=1.5+(DSS-SBB)/DBB                                          21070
        IDSS=MINO(NBB,IDSS)                                             21080
        BS=BB(IDSS)                                                     21090
        ZCR1=(SIGN(1.,DSS)+1.)/2.                                       21100
        DSS=DSS*ZCR1                                                    21110
        A33S=(RHO*PI*BS**2)/8.                                          21120
        A22S=(RHO*.4*PI*DSS**2)/2.                                      21130
        DSR=DS-(XREF-XS)*THETA                                          21140
        ID=1.+(DSR*12.-SDS)/DDS                                         21150
        ID=MAXO(MINO(ID,NDS),1)                                         21160
        DDSR =(ID-1)*DDS +SDS                                           21170
        ID1=MINO(ID+1,NDS)                                              21180
        DID= (DSR*12.-DDSR)/DDS                                         21190
        BCC=ACO( 1,ID,IP)                                               21200
        BCCO=ACCO( 1,ID,IP)                                             21210
        BC2=AC2( 1,ID,IP)                                               21220
        BC5 = AC5(1,ID,IP)                                              21230
        BC6 = AC6(1,ID,IP)                                              21240
        BCC =BCC +DID*(ACO (1,ID1,IP)-BCC ) +DIP*(ACO (1,ID,IP1)-BCC    21250
      1    +DID*(ACO (1,ID1,IP1)-ACO (1,ID,IP1)-ACO (1,ID1,IP)+BCC ))   21260
```

```
      BC00=BC00+DID*(AC00(1,ID1,IP)-BC00) +DIP*(AC00(1,ID,IP1)-BC00      21290
     1    +DID*(AC00(1,ID1,IP1)-AC00(1,ID,IP1)-AC00(1,ID1,IP)+BC00))     21300
      BC2 =BC2 +DID*(AC2 (1,ID1,IP)-BC2 ) +DIP*(AC2 (1,ID,IP1)-BC2       21310
     1    +DID*(AC2 (1,ID1,IP1)-AC2 (1,ID,IP1)-AC2 (1,ID1,IP)+BC2 ))     21320
      BC5 =BC5 +DID*(AC5 (1,ID1,IP)-BC5 ) +DIP*(AC5 (1,ID,IP1)-BC5       21330
     1    +DID*(AC5 (1,ID1,IP1)-AC5 (1,ID,IP1)-AC5 (1,ID1,IP)+BC5 ))     21340
      BC6 =BC6 +DID*(AC6 (1,ID1,IP)-BC6 ) +DIP*(AC6 (1,ID,IP1)-BC6       21350
     1    +DID*(AC6 (1,ID1,IP1)-AC6 (1,ID,IP1)-AC6 (1,ID1,IP)+BC6 ))     21360
                                                                         21370
C     SHIFT MOMENT CENTER FROM XREF TO C.G.                              21380
      BC00 = BC00-(XS-XREF)*BC0                                          21390
      BC6  = BC6 -(XS-XREF)*BC5                                          21400
                                                                         21410
C     HYDROSTATIC AND HYDRODYNAMIC FORCES                                21420
      FZH(J) =-G*BC0-U*U*A33S*THETA-U*A33S*W+Q*U*(-BC2+A33S*XSS)         21430
     1    -U*A33S*P*YLSW                                                 21440
      FMH(J) =-U*XSS*XSS*A33S*Q+G*BC00+U*(A33S*XSS+BC2)*(W+U*THETA       21450
     1  +YLSW*P)                                                        21460
      FYH(J) =-A22S*U*(V+XSS*R  -ZS*P)                                   21470
      FNH(J) = FYH(J)*XSS-U*((V-ZS*P)*BC5+R*BC6)                         21480
      IF (IMT.EQ.2)  GO TO 40                                            21490
                                                                         21500
                                                                         21510
C     CALC OF FORCE ON VENTRAL FINS                                      21520
      VDS=DS-VX*THETA+VSPAN*VCOS                                         21530
      IF (VDS .LE.0.) GO TO 38                                           21540
      VWSPN=AMIN1(VSPAN,VDS/VCOS)                                        21550
      VASPR=VWSPN/VCHORD                                                 21560
      VAREA=VWSPN*VCHORD                                                 21570
      VV=W-VX*Q+PM1*VY*P+U*THETA                                         21580
      VH=V+VX*R-VZ*P                                                     21590
      VPHI=PHI+PM1*VANGLE                                                21600
      VVTOL =  SQRT(VV*VV+VH*VH)                                         21610
      IF (VVTOL.EQ.0.0)  GO TO 38                                        21620
      VVNOR=COS(-ATAN2(VV,VH)+VPHI)*VVTOL                                21630
      VCLA=2.*PI*VASPR/(VASPR+3.)                                        21640
      ENDFAC= (1.+(VDS-VSPAN*VCOS)/VDS)**2                               21650
      VFN=VCLA*(-VVNOR/U)*VAREA*(U*U+V*V)*HRHO                           21660
      VFN=VFN*ENDFAC                                                     21670
      VFYD   =-HRHO*CDSW*VH*ABS(VH)*VAREA*COS(VPHI)                      21680
      VFY(J)=VFN*COS(VPHI) +VFYD                                         21690
      VFZ(J)=VFN*SIN(VPHI)                                               21700
      GOTO 39                                                            21710
   38 VFY(J) = 0.0                                                       21720
      VFZ(J)=0.                                                          21730
      VVNOR=0.0                                                          21740
      VCLA=0.0                                                           21750
      VVNOR=0.0                                                          21760
```

```
39    CONTINUE                                                                21770
                                                                              21780
40    CONTINUE                                                                21790
      IF (IMT.EQ.2)  RETURN                                                   21800
                                                                              21810
C     TOTAL SIDEWALL FORCES AMD MOMENTS                                       21820
      FX=FXH(1)+FXH(2)                                                        21830
      FY=FYH(1)+FYH(2)                                                        21840
      FZ=FZH(1)+FZH(2)                                                        21850
      FK=(FZH(2)-FZH(1))*YSW            +FKD -FY*ZS                           21860
      FY=FY+FYD                                                               21870
      FM=FMH(1)+FMH(2)+ZS*FX                                                  21880
      FN= FND +FNH(1)+FNH(2) +(FXH(1)-FXH(2))*YSW                             21890
                                                                              21900
C     DRAG FORCE ON FINS                                                      21910
      REY=U*VCHORD/ENU                                                        21920
      CFV=.427/(ALOG10(REY)-.407)**2.64                                       21930
      PI8=PI/8.                                                               21940
      CD=2.*CFV+ PI8*VTC*VTC*(1.+G*VSPAN/(U*U))+VCLA*(VVNOR/U)**2             21950
      FXV=-2.*CD*VAREA*HRHO*U*U                                               21960
      FYV=VFY(1)+VFY(2)                                                       21970
      FZV=VFZ(1)+VFZ(2)                                                       21980
      FKV=(VFZ(2)-VFZ(1))*VY-FYV*VZ                                           21990
      FMV=-FZV*VX+FXV*VZ                                                      22000
      FNV=FYV*VX                                                              22010
                                                                              22020
      FX=FX+FXV                                                               22030
      FY=FY+FYV                                                               22040
      FZ=FZ+FZV                                                               22050
      FK=FK+FKV                                                               22060
      FM=FM+FMV                                                               22070
      FN=FN+FNV                                                               22080
      IF (ISIDWL.NE.ON) RETURN                                                22090
      WRITE( 6,123) ((GAP(I,J),J=1,11),I=1,2),((DSW(I,J),J=1,11),I=1,2),22100
     1  FX,FY,FZ,FK,FM,FN                                                     22110
  123 FORMAT(/10X,8HSIDEWALL /25H GAP (FT.) (STERN TO BOW) /14H PORT SID22120
     1EWALL /11F10.5/14H STBD SIDEWALL /11F10.5/37H IMMERSION DEPTH (FT.22130
     2) (STERN TO BOW) /14H PORT SIDEWALL /11F10.5/14H STBD SIDEWALL /  22140
     3 11F10.5/10X,26HSIDEWALL FX,FY,FZ,FK,FM,FN /6E15.4)                   22150
      RETURN                                                                  22160
      END                                                                     22170


      SUBROUTINE STNSL                                                        22180
      INTEGER ON                                                              22190
      COMMON /AIR/ PINF,RHOINF,GAM                                            22200
      COMMON /CONST/ PI,RAD,UO                                                22210
      COMMON / FORSS/ FX,FY,FZ,FK,FM,FN,QL,FMS                                22220
```

```
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM      22230
     1,DELS(4,10),XCP,ZCP                                               22240
      COMMON /GEOMSS/DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10) 22250
     1  ,ARM2S(10)                                                      22260
      COMMON /KSWTCH/ ITHRST                                            22270
      COMMON/LEAKER/ ALEAK,CFSS                                         22280
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,  22290
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO       22300
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,  22310
     -IRUD,IPROP,IAEROD,IRHS                                            22320
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS           22330
     1  ,ELMAXS,YAVGS(10)                                               22340
      COMMON /STSLR/ CPHI,CPHID                                         22350
      COMMON / VALOLD / YOLD(20)                                        22360
      COMMON /VARBLE/ VAL(40)                                           22370
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),CVCLW,NWAVE,BETA,        22380
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                 22390
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR          10/26/72
                                                                        22410
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),       22420
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     22430
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),22440
     3(VAL(24),PB)                                                      22450
      DIMENSION GAP(11),ELSKI(11)                                       22460
      DATA ENU,UWSKI,CLSKI  / 1.28E-5, 0.0,  1.57C8/                    22470
      DO 5 J=1,11                                                       22480
      GAP(J)=0.0                                                        22490
      ELSKI(J)=0.0                                                      22500
    5 CONTINUE                                                          22510
      ALSS=0.0                                                          22520
      FX=0.0                                                            22530
      FZ=0.0                                                            22540
      FK=0.0                                                            22550
      FM=0.0                                                            22560
      FN=0.0                                                            22570
      DELP=PSS-PB                                                       22580
      IF (DELP.LT.0.0) DELP=0.0                                         22590
      PBAR=PB-PINF                                                      22600
                                                                        22610
                                                                        22620
C     CALCULATE ELSKI HERE.                                             22630
      SINDIF=SINTH-COSTH*THETA                                          22640
      COSDIF=COSTH+SINTH*THETA                                          22650
      X1=XSS+ZSS*THETA-XLF*SINDIF                                       22660
      Z1=-Z-ZSS+XSS*THETA-XLF*COSDIF                                    22670
                                                                        22680
C     CALCULATE GAP HERE.                                               22690
      N=NSTA(4)                                                         22700
```

```
      DO 10 K=1,N                                                       22710
      ELSKI(K)=(ETA(4,K)-DETADX(K)*(XX(4,K)-X1)-Z1)+YY(4,K)*PHI         22720
      GAP(K)=-ELSKI(K)                                                  22730
      IF (GAP(K) .LT. 0.0) GAP(K)=0.0                                   22740
   10 CONTINUE                                                          22750
                                                                        22760
      N=NSTA(4)-1                                                       22770
      DO 20 J=1,N                                                       22780
      ELSKIA=(ELSKI(J+1)+ELSKI(J))/2.                                   22790
      IF (ELSKIA.LE.0.0) GO TO 15                                       22800
      IF (ELSKIA.GT.ELMAXS) ELSKIA=ELMAXS                               22810
      ARM1S(J)=XX(4,J)+ELSKIA/2.                                        22820
      ARM2S(J)=ZS-ELSKIA                                                22830
      DFSS(J)=-DELP*ELSKIA*DELYSS                                       22840
      ARG=.5*RHO*U*U*ELSKIA*DELYSS                                      22850
      RESKI =U*ELSKIA/ENU                                               22860
      CDTSKI=.427/(ALOG10(RESKI)-.407)**2.64                            22870
      TSKIS(J) = - ARG*CDTSKI                                           22880
      GO TO 18                                                          22890
   15 DFSS(J) = 0.0                                                     22900
      TSKIS(J) = 0.0                                                    22910
                                                                        22920
   18 CONTINUE                                                          22930
      FX=FX+TSKIS(J)                                                    22940
      FZ=FZ+DFSS(J)                                                     22950
      FK=FK+DFSS(J)*YAVGS(J)                                            22960
      FM=FM-DFSS(J)*ARM1S(J)+TSKIS(J)*ARM2S(J)                          22970
      FN=FN-TSKIS(J)*YAVGS(J)                                           22980
      ALSS=ALSS+(GAP(J)+GAP(J+1))*DELYSS/2.0                            22990
   20 CONTINUE                                                          23000
                                                                        23010
      ALSS=ALSS+ALEAK                                                   23020
      QL=CFSS*ALSS*SQRT(2.*ABS(PBAR)/RHOINF)*SIGN(1.,PBAR)              23030
                                                                        23040
      IF (ISTNSL.NE.ON) RETURN                                          23050
      WRITE(6,100) GAP,ELSKI,FX,FY,FZ,FK,FM,FN                          23060
  100 FORMAT(//12H  STERN SEAL /26H  GAP (FT.) PORT TO STBD.  /11E11.3  23070
     1/28H  ELSKI (FT.) PORT TO STBD.  /11E11.3/10X,23HSTNSL FX,FY,FZ,FK23080
     2,FM,FN /6E15.4)                                                   23090
      RETURN                                                            23100
      END                                                               23110


      FUNCTION T1(X)                                                    23120
      IF(ABS(X)-.1) 10,10,20                                            23130
   10 T1=X*(1.-X*X/10.0)/3.                                             23140
      RETURN                                                            23150
   20 T1=(SIN(X)-X*COS(X))/(X*X)                                        23160
```

```
      RETURN                                                                23170
      END                                                                   23180

      FUNCTION T2(X)                                                        23190
      IF(ABS(X)-.1) 10,10,20                                                23200
10    T2=1.-X*X/6.                                                          23210
      RETURN                                                                23220
20    T2=SIN(X)/X                                                           23230
      RETURN                                                                23240
      END                                                                   23250

      SUBROUTINE WAVES(TIME)                                                23260
      INTEGER ON                                                            23270
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY23280
      COMMON /CONST/ PI,RAD,UO                                              23290
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VCLNOM         23300
     1,DELS(4,10),XCP,ZCP                                                   23310
      COMMON /GEOMBS/DETABX(11),DETABT(11),ARM1B(10),ARM2B(10)              23320
     1 ,DFBS(10),TSKIB(10)                                                  23330
      COMMON /GEOMSS/DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10)     23340
     1 ,ARM2S(10)                                                           23350
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,      23360
     -               AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO            23370
      COMMON /MWAVE/ FXW(2),FYW(2),FZW(2),FKW(2),FMW(2),FNW(2)               23380
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBFGT                                   23390
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,      23400
     -IRUD,IPROP,IAEROD,IRHS                                                23410
      COMMON /RISER/ AMPTC                                                  23420
      COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSW23430
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC          23440
      COMMON /VARBLE/ VAL(40)                                               23450
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),OVCLW,NWAVE,BETA,            23460
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                     23470
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSEET,SINBET,PBBAR               10/26/72
      COMMON /WAVTAB/ NAL,OAL,SAL,NDS,ODS,SDS,NTF,OTF,STH,NBB,DBB,SBB,      23490
     1          AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),           23500
     2          AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                        23510
     3          ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                     23520
     4          AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),           23530
     5          AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                        23540
     6          ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)                      23550
     7          ,BB(36),XREF,RX                                            23560
      DIMENSION WC0(2),WC00(2),WC1(2),WC2(2),WC3(2),WC4(2),WC5(2),WC6(2)23570
     1         ,WC7(2),WC8(2)                                             23580
      DIMENSION WS0(2),WS00(2),WS1(2),WS2(2),WS3(2),WS4(2),WS5(2),WS6(2)23590
     1         ,WS7(2),WS8(2)                                             23600
```

```
      EQUIVALENCE                    (VAL(2),U),(VAL(3),V),(VAL(4),W),        23610
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),          23620
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),23630
     3(VAL(24),PB)                                                          23640
      EQUIVALENCE (VAL(16),ETACG)                                           23650
                                                                            23660
      IF (NWAVE.EQ.0) RETURN                                                23670
                                                                            23680
      GAMMA=BETA-PSI                                                        23690
      SIGAM=SIN(GAMMA)                                                      23700
      COGAM=COS(GAMMA)                                                      23710
      FC= -X*COSBET -Y*SINBET                                               23720
                                                                            23730
      DVOLW=0.0                                                             23740
      ETACG=0.0                                                             23750
      N=NSTA(3)                                                             23760
      DO 1 J=1,N                                                            23770
      DETABX(J)=0.0                                                         23780
    1 CONTINUE                                                              23790
      N=NSTA(4)                                                             23800
      DO 2 J=1,N                                                            23810
      DETADX(J)=0.0                                                         23820
    2 CONTINUE                                                              23830
      DO 10 J=1,4                                                           23840
      N=NSTA(J)                                                             23850
      DO 10 K=1,N                                                           23860
   10 ETA(J,K)=0.0                                                          23870
      DO 15 J=1,2                                                           23880
      FXW(J) = 0.0                                                          23890
      FYW(J) = 0.0                                                          23900
      FZW(J) = 0.0                                                          23910
      FKW(J) = 0.0                                                          23920
      FMW(J) = 0.0                                                          23930
      FNW(J) = 0.0                                                          23940
   15 CONTINUE                                                              23950
                                                                            23960
      XSS = -XS                                                             23970
      IF (IMT.EQ.2)  XSS = XMI(IX)                                          23980
                                                                            23990
      IP = 1  +(THEBAR*RAD-STH)/DTH                                         24000
      IP=MAXO(MINO(IP,NTH),1)                                               24010
      IP1=MINO(IP+1,NTH)                                                    24020
      DTHETA=(IP-1)*DTH+STH                                                 24030
      DIP= (THETA*RAD-DTHETA)/DTH                                           24040
                                                                            24050
C     TIME RISE FACTOR FOR WAVE AMPLITUDE                                   24060
      AMPFAC=1.-EXP(-TIME/AMPTC)                                            24070
      DO 100 I=1,NWAVE                                                      24080
```

```
      OM1=OMEGA(I)                                                      24090
      OM2=OM1*OM1                                                       24100
      XWK=OM2/G                                                         24110
      AA=AW(I)*AMPFAC                                                   24120
      FT= OM1*TIME+XWK*FO                                               24130
      AL=XWK*COGAM                                                      24140
                                                                        24150
      IAA= 1+(ABS(AL)-SAL)/DAL                                          24160
      IAA=MAXO(MINO(IAA,NAL),1)                                         24170
      IAA1=MINO(IAA+1,NAL)                                              24180
      DAA= (IAA-1)*DAL+SAL                                              24190
      DIA= (ABS(AL)-DAA)/DAL                                            24200
      SALP=SIGN(1.,AL)                                                  24210
                                                                        24220
C     WAVE FORCES AND MOMENTS ON THE SIDEWALLS                          24230
      DO 40 J=1,2                                                       24240
      YLSW=(2*J-3)*YSW                                                  24250
      WE=FT+XWK*SIGAM*YLSW                                              24260
      ST=SIN(WE)                                                        24270
      CT=COS(WE)                                                        24280
      DS= ZBAR+ZS+YLSW*PHIBAR                                           24290
      DSR=DS-(XREF-XS)*THEBAR                                           24300
      ID=1.+(DSR*12.-SDS)/DDS                                           24310
      ID=MAXO(MINO(ID,NDS),1)                                           24320
      DDSR =(ID-1)*DDS +SDS                                             24330
      DID= (DSR*12.-DDSR)/DDS                                           24340
      ID1=MINO(ID+1,NDS)                                                24350
      DSS=DS-XSS*THEBAR                                                 24360
      ZOR1=(SIGN(1.,DSS)+1.)/2.                                         24370
      DSS=DSS*ZOR1                                                      24380
      IDSS=1.5+(DSS-SBB)/DBB                                            24390
      IDSS=MINO(NBB,IDSS)                                               24400
      BS=BB(IDSS)                                                       24410
      CK = COS(XWK*COGAM*XSS)                                           24420
      A33S=(RHO*PI*BS**2)/8.                                            24430
      SK = SIN(XWK*COGAM*XSS)                                           24440
      A22S=(RHO*.4*PI*DSS**2)/2.                                        24450
      A42S=0.0                                                          24460
                                                                        24470
C     INTERPOLATION OF WAVE TABLES                                      24480
      K=1                                                               24490
      L=IAA                                                             24500
41    CONTINUE                                                          24510
      BCC=ACO( L,ID,IP)                                                 24520
      BCCO=ACCO( L,ID,IP)                                               24530
      BC1=AC1( L,ID,IP)                                                 24540
      BC2=AC2( L,ID,IP)                                                 24550
      BC3=AC3( L,ID,IP)                                                 24560
```

```
      BC4=AC4( L,ID,IP)                                                          24570
      BC5=AC5( L,ID,IP)                                                          24580
      BC6=AC6( L,ID,IP)                                                          24590
      BC7=AC7( L,ID,IP)                                                          24600
      BC8=AC8( L,ID,IP)                                                          24610
      BS0=AS0( L,ID,IP)                                                          24620
      BSOO=ASOO( L,ID,IP)                                                        24630
      BS1=AS1( L,ID,IP)                                                          24640
      BS2=AS2( L,ID,IP)                                                          24650
      BS3=AS3( L,ID,IP)                                                          24660
      BS4=AS4( L,ID,IP)                                                          24670
      BS5=AS5( L,ID,IP)                                                          24680
      BS6=AS6( L,ID,IP)                                                          24690
      BS7=AS7( L,ID,IP)                                                          24700
      BS8=AS8( L,ID,IP)                                                          24710
      WC0 (K)=BC0 +DID*(AC0 (L,ID1,IP)-BC0 ) +DIP*(AC0 (L,ID,IP1)-BC0            24720
     1    +DID*(AC0 (L,ID1,IP1)-AC0 (L,ID,IP1)-AC0 (L,ID1,IP)+BC0 ))             24730
      WC00(K)=BC00+DID*(AC00(L,ID1,IP)-BC00) +DIP*(AC00(L,ID,IP1)-BC00           24740
     1    +DID*(AC00(L,ID1,IP1)-AC00(L,ID,IP1)-AC00(L,ID1,IP)+BC00))             24750
      WC1 (K)=BC1 +DID*(AC1 (L,ID1,IP)-BC1 ) +DIP*(AC1 (L,ID,IP1)-BC1            24760
     1    +DID*(AC1 (L,ID1,IP1)-AC1 (L,ID,IP1)-AC1 (L,ID1,IP)+BC1 ))             24770
      WC2 (K)=BC2 +DID*(AC2 (L,ID1,IP)-BC2 ) +DIP*(AC2 (L,ID,IP1)-BC2            24780
     1    +DID*(AC2 (L,ID1,IP1)-AC2 (L,ID,IP1)-AC2 (L,ID1,IP)+BC2 ))             24790
      WC3 (K)=BC3 +DID*(AC3 (L,ID1,IP)-BC3 ) +DIP*(AC3 (L,ID,IP1)-BC3            24800
     1    +DID*(AC3 (L,ID1,IP1)-AC3 (L,ID,IP1)-AC3 (L,ID1,IP)+BC3 ))             24810
      WC4 (K)=BC4 +DID*(AC4 (L,ID1,IP)-BC4 ) +DIP*(AC4 (L,ID,IP1)-BC4            24820
     1    +DID*(AC4 (L,ID1,IP1)-AC4 (L,ID,IP1)-AC4 (L,ID1,IP)+BC4 ))             24830
      WC5 (K)=BC5 +DID*(AC5 (L,ID1,IP)-BC5 ) +DIP*(AC5 (L,ID,IP1)-BC5            24840
     1    +DID*(AC5 (L,ID1,IP1)-AC5 (L,ID,IP1)-AC5 (L,ID1,IP)+BC5 ))             24850
      WC6 (K)=BC6 +DID*(AC6 (L,ID1,IP)-BC6 ) +DIP*(AC6 (L,ID,IP1)-BC6            24860
     1    +DID*(AC6 (L,ID1,IP1)-AC6 (L,ID,IP1)-AC6 (L,ID1,IP)+BC6 ))             24870
      WC7 (K)=BC7 +DID*(AC7 (L,ID1,IP)-BC7 ) +DIP*(AC7 (L,ID,IP1)-BC7            24880
     1    +DID*(AC7 (L,ID1,IP1)-AC7 (L,ID,IP1)-AC7 (L,ID1,IP)+BC7 ))             24890
      WC8 (K)=BC8 +DID*(AC8 (L,ID1,IP)-BC8 ) +DIP*(AC8 (L,ID,IP1)-BC8            24900
     1    +DID*(AC8 (L,ID1,IP1)-AC8 (L,ID,IP1)-AC8 (L,ID1,IP)+BC8 ))             24910
      WS0 (K)=BS0 +DID*(AS0 (L,ID1,IP)-BS0 ) +DIP*(AS0 (L,ID,IP1)-BS0            24920
     1    +DID*(AS0 (L,ID1,IP1)-AS0 (L,ID,IP1)-AS0 (L,ID1,IP)+BS0 ))             24930
      WS00(K)=BS00+DID*(AS00(L,ID1,IP)-BS00) +DIP*(AS00(L,ID,IP1)-BS00           24940
     1    +DID*(AS00(L,ID1,IP1)-AS00(L,ID,IP1)-AS00(L,ID1,IP)+BS00))             24950
      WS1 (K)=BS1 +DID*(AS1 (L,ID1,IP)-BS1 ) +DIP*(AS1 (L,ID,IP1)-BS1            24960
     1    +DID*(AS1 (L,ID1,IP1)-AS1 (L,ID,IP1)-AS1 (L,ID1,IP)+BS1 ))             24970
      WS2 (K)=BS2 +DID*(AS2 (L,ID1,IP)-BS2 ) +DIP*(AS2 (L,ID,IP1)-BS2            24980
     1    +DID*(AS2 (L,ID1,IP1)-AS2 (L,ID,IP1)-AS2 (L,ID1,IP)+BS2 ))             24990
      WS3 (K)=BS3 +DID*(AS3 (L,ID1,IP)-BS3 ) +DIP*(AS3 (L,ID,IP1)-BS3            25000
     1    +DID*(AS3 (L,ID1,IP1)-AS3 (L,ID,IP1)-AS3 (L,ID1,IP)+BS3 ))             25010
      WS4 (K)=BS4 +DID*(AS4 (L,ID1,IP)-BS4 ) +DIP*(AS4 (L,ID,IP1)-BS4            25020
     1    +DID*(AS4 (L,ID1,IP1)-AS4 (L,ID,IP1)-AS4 (L,ID1,IP)+BS4 ))             25030
      WS5 (K)=BS5 +DID*(AS5 (L,ID1,IP)-BS5 ) +DIP*(AS5 (L,ID,IP1)-BS5            25040
```

```
     1    +DID*(AS5 (L,ID1,IP1)-AS5 (L,ID,IP1)-AS5 (L,ID1,IP)+BS5 ))      25050
      WS6 (K)=BS6 +DID*(AS6 (L,ID1,IP)-BS6 ) +DIP*(AS6 (L,ID,IP1)-BS6    25060
     1    +DID*(AS6 (L,ID1,IP1)-AS6 (L,ID,IP1)-AS6 (L,ID1,IP)+BS6 ))     25070
      WS7 (K)=BS7 +DID*(AS7 (L,ID1,IP)-BS7 ) +DIP*(AS7 (L,ID,IP1)-BS7    25080
     1    +DID*(AS7 (L,ID1,IP1)-AS7 (L,ID,IP1)-AS7 (L,ID1,IP)+BS7 ))     25090
      WS8 (K)=BS8 +DID*(AS8 (L,ID1,IP)-BS8 ) +DIP*(AS8 (L,ID,IP1)-BS8    25100
     1    +DID*(AS8 (L,ID1,IP1)-AS8 (L,ID,IP1)-AS8 (L,ID1,IP)+BS8 ))     25110
      IF(K .EQ. 2) GOTO 42                                               25120
      K=2                                                                25130
      L =IAA1                                                            25140
      GOTO 41                                                            25150
42    BC0 =  WC0 (1)+DIA*(WC0 (2)-WC0 (1))                               25160
      BC00=  WC00(1)+DIA*(WC00(2)-WC00(1))                               25170
      BC1 =  WC1 (1)+DIA*(WC1 (2)-WC1 (1))                               25180
      BC2 =  WC2 (1)+DIA*(WC2 (2)-WC2 (1))                               25190
      BC3 =  WC3 (1)+DIA*(WC3 (2)-WC3 (1))                               25200
      BC4 =  WC4 (1)+DIA*(WC4 (2)-WC4 (1))                               25210
      BC5 =  WC5 (1)+DIA*(WC5 (2)-WC5 (1))                               25220
      BC6 =  WC6 (1)+DIA*(WC6 (2)-WC6 (1))                               25230
      BC7 =  WC7 (1)+DIA*(WC7 (2)-WC7 (1))                               25240
      BC8 =  WC8 (1)+DIA*(WC8 (2)-WC8 (1))                               25250
      BS0 =(WS0 (1)+DIA*(WS0 (2)-WS0 (1)))*SALP                          25260
      BS00=(WS00(1)+DIA*(WS00(2)-WS00(1)))*SALP                          25270
      BS1 =(WS1 (1)+DIA*(WS1 (2)-WS1 (1)))*SALP                          25280
      BS2 =(WS2 (1)+DIA*(WS2 (2)-WS2 (1)))*SALP                          25290
      BS3 =(WS3 (1)+DIA*(WS3 (2)-WS3 (1)))*SALP                          25300
      BS4 =(WS4 (1)+DIA*(WS4 (2)-WS4 (1)))*SALP                          25310
      BS5 =(WS5 (1)+DIA*(WS5 (2)-WS5 (1)))*SALP                          25320
      BS6 =(WS6 (1)+DIA*(WS6 (2)-WS6 (1)))*SALP                          25330
      BS7 =(WS7 (1)+DIA*(WS7 (2)-WS7 (1)))*SALP                          25340
      BS8 =(WS8 (1)+DIA*(WS8 (2)-WS8 (1)))*SALP                          25350
                                                                         25360
C     SHIFT MOMENT CENTER FROM XREF TO C.G.                              25370
      BC00 = BC00-(XS-XREF)*BC0                                          25380
      BC3  = BC3 -(XS-XREF)*BC1                                          25390
      BC4  = BC4 -(XS-XREF)*BC2                                          25400
      BC6  = BC6 -(XS-XREF)*BC5                                          25410
      BS00 = BS00-(XS-XREF)*BS0                                          25420
      BS3  = BS3 -(XS-XREF)*BS1                                          25430
      BS4  = BS4 -(XS-XREF)*BS2                                          25440
      BS6  = BS6 -(XS-XREF)*BS5                                          25450
                                                                         25460
C     CALCULATE WAVE FORCES AND MOMENTS                                  25470
      FZC= BS1-XWK*G*(BS2+BS0)-U*OM1*(-A33S*CK-AL*BS2)                   25480
      FZS= BC1-XWK*G*(BC2+BC0)+U*OM1*(-A33S*SK+AL*BC2)                   25490
      FMC= BS3-XWK*G*(BS4+BS00)-U*OM1*(-A33S*XSS*CK-BC2-AL*BS4)          25500
      FMS= BC3-XWK*G*(BC4+BC00)+U*OM1*(-A33S*XSS*SK-BS2+AL*BC4)          25510
      FYC= XWK*G*(BC5+BC0)-U*OM1*(-A22S*SK+AL*BC5)                       25520
```

```
      FYS= -XWK*G*(BS5+BSC)-U*OM1*(-A22S*CK-AL*BS5)                          25530
      FNC= XWK*G*(BC6+BC00)-U*OM1*(-A22S*XSS*SK-BS5+AL*BC6)                  25540
      FNS= -XWK*G*(BS6+BS00)-U*OM1*(-A22S*XSS*CK-BC5-AL*BS6)                 25550
      FKC=XWK*G*(BC7-BC8)+U*OM1*(-A42S*SK+AL*BC8)                            25560
      FKS= -XWK*G*(BS7-BS8)+U*OM1*(-A42S*CK-AL*BS8)                          25570
      FZW(J)=FZW(J)-AA*(FZC*CT+FZS*ST)                                       25580
      FMW(J)=FMW(J)+AA*(FMC*CT+FMS*ST)                                       25590
      FYW(J)=FYW(J)-AA*(FYC*CT+FYS*ST)*SIGAM                                 25600
      FNW(J)=FNW(J)-AA*(FNC*CT+FNS*ST)*SIGAM                                 25610
      FKW(J)=FKW(J)-AA*(FKC*CT+FKS*ST)*SIGAM                                 25620
      FXW(J)= FXW(J)-2.*AA*RHO*G*BS*DSS*SK*CT                                25630
   40 CONTINUE                                                               25640
      IF (IMT.EQ.2)  GO TO 100                                               25650
                                                                             25660
C     WAVE ELEVATION AROUND THE SIDEWALLS AND SEALS                          25670
      DO 20 J=1,4                                                            25680
      N=NSTA(J)                                                              25690
      DO 20 K=1,N                                                            25700
      ETA(J,K)=ETA(J,K)+SIN(XWK*(- XX(J,K)*COGAM-YY(J,K)*SIGAM)+FT)*AA       25710
20    CONTINUE                                                               25720
      ETACG=ETACG+AA*SIN(FT)                                                 25730
      N=NSTA(3)                                                              25740
      DO 25 J=1,N                                                            25750
      ARG=AA*COS(XWK*(-XX(3,J)*COGAM)+FT)                                    25760
      DETABX(J)=DETABX(J)-XWK*COGAM*ARG                                      25770
   25 CONTINUE                                                               25780
      N=NSTA(4)                                                              25790
      DO 30 J=1,N                                                            25800
      ARG=AA*COS(XWK*(-XX(4,J)*COGAM)+FT)                                    25810
      DETADX(J)=DETADX(J)-XWK*COGAM*ARG                                      25820
   30 CONTINUE                                                               25830
                                                                             25840
C     WAVE PUMPING                                                           25850
      X1=XWK*XLBW*COGAM/2.                                                   25860
      X2=XWK*XBBW*SIGAM/2.                                                   25870
      FTT=FT-XWK*XCP*COGAM                                                   25880
      DVOLW=DVOLW+AA*ABW*T2(X1)*T2(X2)*SIN(FTT)                              25890
                                                                             25900
100   CONTINUE                                                               25910
      IF (IMT.EQ.2)  RETURN                                                  25920
                                                                             25930
C     TOTAL WAVE FORCES AND MOMENTS                                          25940
      FXWAV=FXW(1)+FXW(2)                                                    25950
      FYWAV=FYW(1)+FYW(2)                                                    25960
      FZWAV=FZW(1)+FZW(2)                                                    25970
      FKWAV=FKW(1)+FKW(2)+(FZW(2)-FZW(1))*YSW      +FYWAV*ZBAR               25980
      FMWAV=FMW(1)+FMW(2)-FXWAV*ZBAR                                         25990
      FNWAV=FNW(1)+FNW(2)+(FXW(1)-FXW(2))*YSW                                26000
```

```
      IF (IWAVES.NE.ON) RETURN                                          26010
                  WRITE(6,200) ((ETA(I,J),J=1,11),I=1,4),ETACG,DVOLW    26020
     1,FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                              26030
  200 FORMAT(/10X,5HWAVES /63H WAVE ELEVATIONS AT CRAFT STATIONS RELATIV26040
     1E TO CALM WATER (FT.) /14H PORT SIDEWALL /11F10.5/14H STBD SIDEWAL26050
     2L /11F10.5/9H BOW SEAL /11F10.5/11H STERN SEAL /11F10.5/25H WAVE E26060
     3LEVATION AT C.G. = F10.5,10X,43HPLENUM VOLUME LOST DUE TO WAVES (C26070
     4U. FT.) = F15.5/10X,23HWAVES FX,FY,FZ,FK,FM,FN /6E15.4)           26080
      RETURN                                                            26090
      END                                                               26100

      BLOCK DATA                                                        26110
      COMMON /AIR/ Z1(3)                                                26120
      COMMON /BMCO/ Z2(25)                                              26130
      COMMON /COLUMN / Z3(2)                                            26140
      COMMON /CONST/ Z4(3)                                              26150
      COMMON /CNTRL/ Z5(10)                                             26160
      COMMON /ENGINE/ Z6(7)                                             26170
      COMMON /EQNCO/ Z7(22)                                             26180
      COMMON /FAERO/ Z8(6)                                              7/4/73
      COMMON /FAIR/ Z9(2)                                               26200
      COMMON /FANMAP/ Z10(160)                                          26210
      COMMON /FORBS/ Z11(7)                                             26220
      COMMON /FORSS/Z12(8)                                              26230
      COMMON /FPROP/ Z13(6)                                             26240
      COMMON /FROUDE/ Z14(2)                                            26250
      COMMON /FRUD/ Z15(6)                                              26260
      COMMON /GBOW/ Z16(1)                                              26270
      COMMON /GEOM/ Z17(138)                                            26280
      COMMON /GEOMBS/ Z18(62)                                           26290
      COMMON /GEOMSS/ Z19(62)                                           26300
      COMMON /GEOMSW/ Z20(11)                                           26310
      COMMON /KSWTCH/ Z21(1)                                            26320
      COMMON /LEAKER/ Z22(2)                                            26330
      COMMON /MASSES/ Z23(817)                                          26340
      COMMON /MATRIX/ Z24(36)                                           26350
      COMMON /MSIDW/ Z25(55)                                            26360
      COMMON /MWAVE/ Z26(12)                                            26370
      COMMON /OPTION/ Z27(3)                                            26380
      COMMON /PLENUM/ Z28(4)                                            26390
      COMMON /PLVCQQ/ Z28A(4)                                           26400
      COMMON /PRIME/ Z29(5)                                             3/3/73
      COMMON /PRTINT/ Z30(12)                                           26410
      COMMON /PWAVE/ Z31(2)                                             26420
      COMMON /RISER/ Z32(1)                                             26430
      COMMON /ROLL/ Z33(2)                                              26440
                                                                        26450
```

```
      COMMON /RUDDR/ Z34(20)                                            2/28/73
      COMMON /SIDE/ Z35(22)                                             26470
      COMMON /SOFTBS/ Z36(25)                                           26480
      COMMON /SOFTSS/ Z37(19)                                           26490
      COMMON /STABLE/ Z38(5)                                            26500
      COMMON /STSLR/ Z39(2)                                             26510
      COMMON /VALOLD/ Z40(20)                                           26520
      COMMON /VARBLE/ Z41(40)                                           26530
      COMMON /WAVE/ Z42(80)                                             10/26/72
      COMMON /WAVEF / Z43(40)                                           26550
      DATA Z1/3*0.0/                                                    26560
      DATA Z2/25*0.0/                                                   26570
      DATA Z3/2*0.0/                                                    26580
      DATA Z4/3*0.0/                                                    26590
      DATA Z5/10*0.0/                                                   26600
      DATA Z6/7*0.0/                                                    26610
      DATA Z7/21*0.0/                                                   26620
      DATA Z8/6*0.0/                                                    26630
      DATA Z9/2*0.0/                                                    26640
      DATA Z10/160*0.0/                                                 26650
      DATA Z11/7*0.0/                                                   26660
      DATA Z12/8*0.0/                                                   26670
      DATA Z13/6*0.0/                                                   26680
      DATA Z14/2*0.0/                                                   26690
      DATA Z15/6*0.0/                                                   26700
      DATA Z16/0.0/                                                     26710
      DATA Z17/138*0.0/                                                 26720
      DATA Z18/62*0.0/                                                  26730
      DATA Z19/62*0.0/                                                  26740
      DATA Z20/11*0.0/                                                  26750
      DATA Z21/0.0/                                                     26760
      DATA Z22/2*0.0/                                                   26770
      DATA Z23/817*0.0/                                                 26780
      DATA Z24/36*0.0/                                                  26790
      DATA Z25/55*0.0/                                                  26800
      DATA Z26/12*0.0/                                                  26810
      DATA Z27/3*0.0/                                                   26820
      DATA Z28/4*0.0/                                                   26830
      DATA Z28A/4*0.0/                                                  3/3/73
      DATA Z29/5*0.0/                                                   26840
      DATA Z30/12*0.0/                                                  26850
      DATA Z31/2*0.0/                                                   26860
      DATA Z32/0.0/                                                     26870
      DATA Z33/2*0.0/                                                   26880
      DATA Z34/20*0.0/                                                  2/28/73
      DATA Z35/22*0.0/                                                  26900
      DATA Z36/25*0.0/                                                  26910
      DATA Z37/19*0.0/                                                  26920
```

```
      DATA Z38/5*0.C/                                                    26930
      DATA Z39/2*0.0/                                                    26940
      DATA Z40/20*0.0/                                                   26950
      DATA Z41/40*0.0/                                                   26960
      DATA Z42/80*0.0/                                                   10/26/72
      DATA Z43/40*0.0/                                                   26980
      END                                                                26990
THE FOLLOWING LISTING IS THE TABLE LOCK-UP ROUTINE FOR THE SIDEWALL AND
APPENDAGES NOT INCLUDED IN THE MAIN PROGRAM.
C  SIDETAB PROGRAM FOR COMPUTING SIDEWALL TABLE OF FORCES AND MOMENTS
      DIMENSION FC1(95),FC2(95),FC3(95),FC4(95),FC5(95),FC6(95),FC7(95) 00010
     1          ,FC0(95),FC00(95),FC8(95)                               00020
      DIMENSION FS1(95),FS2(95),FS3(95),FS4(95),FS5(95),FS6(95),FS7(95) 00030
     1          ,FS0(95),FS00(95),FS8(95)                               00040
      DIMENSION Z(14050),XIN(10)                                         00050
      COMMON /ATAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,     00060
     1          AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),        00070
     2          AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                     00080
     3          ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                  00090
     4          AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),        00100
     5          AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                     00110
     6          ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7),BB(36),XREF,RX    00120
      EQUIVALENCE (Z,NAL)                                                00130
      COMMON     XX(95),ZZ(8,95),YY(8,95),XXX                            00140
      DATA G,RHO/32.2,2./                                                00150
      NAMELIST/INPUT/NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,    00160
     1  NSTA,ND,DRMAX,XREF,NIN,XIN                                       00170
                                                                         00180
C     THIS PROGRAM EVALUATES INTEGRALS THAT ARE NECESSARY FOR THE EVALUA00190
C     THE HYDROSTATIC AND HYDRODYNAMIC FORCES AND MOMENTS FOR A SINGLE S00200
C     AS A FUNCTION OF DRAFT,TRIM AND WAVELENGTH.                        00210
C     CECK SET UP FOR BELL 100 TON CRAFT - 27 APRIL 1971                 00220
                                                                         00230
                                                                         00240
C     READ INTEGRAL TABLE PARAMETERS                                     00250
      RX=0.0                                                             00260
      READ(5,990) NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB        00270
C     READ NO. OF STATIONS AND MAX. NO. OF DRAFTS/STATIONS               00280
      READ(5,991) NSTA,ND                                                00290
C     READ MAX. DRAFT                                                    00300
      READ(5,900) DRMAX                                                  00310
                                                                         00320
C     READ REFERENCE POSITION + INTEGRAL LIMITS (DISTANCES FROM TRANSOM)00330
      READ  (5,906) XREF                                                 00340
      READ  (5,907) NIN,( XIN(I),I=1,NIN)                                00350
      IF ( NIN.GT.10 )  GO TO 211                                        00360
      WRITE(6,INPUT)                                                     00370
      IF (SAL .NE. 0.) GOTO 212                                          00380
```

```
      PI=4.*ATAN(1.)                                                    00390
      RAD =180./PI                                                      00400
      WRITE (6,999)                                                     00410
                                                                        00420
C     READ OFFSET DATA (BOW TO STERN)                                   00430
C     XX IS LONGITUDINAL DISTANCE OF STATION FROM BOW - INCHES          00440
C     YY IS LOCAL WATERLINE BEAM - FEET                                 00450
C     ZZ IS CORRESPONDING HEIGHT OF LOCAL BEAM - FEET                   00460
      DO 40 J=1,NSTA                                                    00470
      READ(5,900) XX(J),((ZZ(I,J),YY(I,J)),I=1,ND)                     00480
      JJ=J-1                                                            00490
      WRITE(6,903) JJ,XX(J),((ZZ(I,J),YY(I,J)),I=1,ND)                  00500
40    CONTINUE                                                          00510
C     CONVERT XX(INCHES) TO XX(FEET)                                    00520
      DO 41 J=1,NSTA                                                    00530
41    XX(J) =XX(J)/12.                                                  00540
      XRAF = XX(NSTA)-XREF                                              00550
                                                                        00560
                                                                        00570
C     GENERATE TABLES FOR SIDEWALLS AND WAVES                           00580
      MSTA=NSTA                                                         00590
      NINI = NIN+1                                                      00600
      DO 101 IN=1,NINI                                                  00610
      NSTA = MSTA                                                       00620
      IF (IN.EQ.1)  GO TO 48                                            00630
      XXX = XX(MSTA)-XIN(IN-1)                                          00640
      GO TO 49                                                          00650
   48 XXX = XX(MSTA)                                                    00660
   49 XINT = XRAF-XXX                                                   00670
                                                                        00680
      DO 100 IA=1,NAL                                                   00690
      AL = SAL+DAL*(IA-1)                                               00700
      DO 100 ID=1,NDS                                                   00710
      DS =(SDS+DDS*(ID-1))/12.0                                         00720
      DO 100 IP=1,NTH                                                   00730
      TH =(STH+DTH*(IP-1))/RAD                                          00740
                                                                        00750
      DO 80 J=1,NSTA                                                    00760
      JJ=J-1                                                            00770
      X=XRAF-XX(J)                                                      00780
      IF ( X.LE.XINT )  NSTA = J                                        00790
      DX=DS-TH*X                                                        00800
                                                                        00810
      IF (DX .GT. DRMAX)  DX = DRMAX                                    00820
      IF(DX) 50,50,60                                                   00830
   50 DX=0.                                                             00840
                                                                        00850
                                                                        00860
```

```
      B=0.                                                              00870
      S=0.                                                              00880
      ZB=0.0                                                            00890
      A33=0.                                                            00900
      A22=0.                                                            00910
      A42=0.                                                            00920
      GOTO 70                                                           00930
   60 CONTINUE                                                          00940
                                                                        00950
C     CALCULATE AREA + CENTER OF BUOYANCY (IF DX .GT. 0)                00960
      S=0.                                                              00970
      DSZ=0.                                                            00980
      I=1                                                               00990
105   Z1=ZZ(I,J)                                                       01000
      Z2=ZZ(I+1,J)                                                      01010
      Y1=YY(I,J)                                                        01020
      Y2=YY(I+1,J)                                                      01030
      K=1                                                               01040
      DZ=Z2-Z1                                                          01050
      IF(DZ .EQ. 0.) GO TO 50                                           01060
      IF(DX-Z1 .LE. 0.) GO TO 50                                        01070
      IF(DX-Z2 .LE. 0.) GOTO 120                                        01080
110   CONTINUE                                                          01090
      S=S+DZ*(Y1+Y2)/2.                                                 01100
      SPIN=(Y2-Y1)/DZ                                                   01110
      BX=(Y1*Z2-Z1*Y2)/DZ                                               01120
      DSZ0=BX*(Z2*Z2-Z1*Z1)/2. +SPIN*(Z2*Z2*Z2-Z1*Z1*Z1)/3.             01130
      DSZ=DSZ+DSZ0                                                      01140
      I=I+1                                                             01150
      GO TO (105,130),K                                                 01160
120   K=2                                                               01170
      Y2=Y1+(DX-Z1)*(Y2-Y1)/DZ                                          01190
      Z2=DX                                                             01200
      DZ=Z2-Z1                                                          01210
      GOTO 110                                                          01220
130   CONTINUE                                                          01230
      ZB=DX-DSZ/S                                                       01240
      DX = DX-ZZ(1,J)                                                   01250
      B=Y2                                                              01260
      A33=(RHO*PI*B**2)/8.                                              01270
      A22=(RHO*.4*PI*DX**2)/2.                                          01280
      A42=(RHO*PI*DX**3)/4.                                             01290
   70 CONTINUE                                                          01300
      F0=S                                                              01310
      F00=F0*X                                                          01320
      F1=B                                                              01330
      F2=A33                                                            01340
      F3=F1*X                                                           01350
```

```
F4=F2*X                                                          01360
F5=A22                                                           01370
F6=F5*X                                                          01380
F7=B**3/12.-S*ZB                                                 01390
F8=A42                                                           01400
CAX=COS(-AL*X)                                                   01410
SAX=SIN(-AL*X)                                                   01420
IX=J                                                             01430
FC0(IX)=F0*CAX                                                   01440
FC00(IX)=F00*CAX                                                 01450
FC1(IX)=F1*CAX                                                   01460
FC2(IX)=F2*CAX                                                   01470
FC3(IX)=F3*CAX                                                   01480
FC4(IX)=F4*CAX                                                   01490
FC5(IX)=F5*CAX                                                   01500
FC6(IX)=F6*CAX                                                   01510
FC7(IX)=F7*CAX                                                   01520
FC8(IX)=F8*CAX                                                   01530
FS0(IX)=F0*SAX                                                   01540
FS00(IX)=F00*SAX                                                 01550
FS1(IX)=F1*SAX                                                   01560
FS2(IX)=F2*SAX                                                   01570
FS3(IX)=F3*SAX                                                   01580
FS4(IX)=F4*SAX                                                   01590
FS5(IX)=F5*SAX                                                   01600
```

```
THE FOLLOWING IS A TYPICAL INPUT DATA DECK UTILIZING SES/BH8
00101    0.0        25.0        .005        0.5
00102
     C     0     0     0     0     0     0     0     0     0     0     0
00103
1001
   .0000001   .0000001      .00005   .0000001   .0000001   .0000001   .0000001   .0000001
   .0000001   .00001
00104
     1     1
C0201209999.31333.092      7.092      1073780.002769405.003635907.00-99900.313
00301   11.0       11.0        5.0         5.0       72.0
00401   15.54      60.0         .7         1.28       1.36
00402   30.         3.0         3.0        15.0      14.875       -1.5          .075
00501 7.5          5.479      25.52        .90       55.5         26.          9.101
00601 53.07        .60        24.         3.75
00701 65.31        31.16                  28.00      65.31        33.4         6.17
00702 .6
00901  6.125       15.6        -1.5        3.0        1.4         6.375         .108
01001 63.15        31.65
01102     1.0         90.0
720.0      0.5
01901 1.           1700.       17.         1.         1700.
 0.          33.          62.          87.          106.         118.         128.         133.
 137.        139.         141.         143.         146.         152.         160.         180.
 200.
1185.        1100.        1000.        900.         800.         700.         600.         500.
 400.        300.         100.         -50.         -95.         -145.        -175.        -220.
-235.
C1902 5.           1700.       16.         1.         1700.
 0.          28.          54.          76.          91.          104.         112.         118.
 120.        121.         122.         126.         133.         142.         160.         176.
 1195.       1100.        1000.        900.         800.         700.         600.         500.
 400.        0.           -50.         -100.        -150.        -180.        -220.        -240.
C1903 2.           1870.       17.         1.         1870.
 0.          9.           42.          70.          94.          114.         127.         136.
 144.        147.         150.         151.         154.         160.         180.         200.
 213.
 1340.       1300.        1200.        1100.        1000.        900.         800.         700.
 600.        500.         400.         0.           -100.        -165.        -215.        -245.
-260.
018
20.0 DEGREE TURN WITH WAVES
C08C1-1.0        15.75       0.9          11646.80   3960.                                  100
01201100.0          .600         4.044       92.80
013
C14
```

LIST OF REFERENCES

1. Department of the Navy, Surface Effects Ship Project Office, Contract No. C-1-35055, SES Motions and Loads Program Users Manual, by James Bentson, Theodore P. Sargent and Alfred I. Raff, August 1971.

2. Cagle, Lonnie F., Some Performance Characteristics of the Bell 100 Ton Surface Effects Ship, Master's Thesis, Naval Postgraduate School, Monterey, California, June, 1973.

3. Department of the Navy, Surface Effects Ship Project Office, Report Contract NO C-1-35055, A Study of Surface Effects Ship (SES), Loads and Motions, Part I - Equations of Motion of SES Craft with Six Degrees of Freedom, by James Bentson, Paul Kaplan, and Theodore P. Sargent, August, 1971.

4. Joint Surface Effects Ship Project Office, Contract #9132FR-1, Surface Effects Ship Program Final Report, Volume II, Aerojet-General Corporation, El Monte, California, May 1969.

5. Naval Ship Research and Development Center, Project SR 009 01 01, Task 0102, Standard Equations of Motion for Submarine Simulation, by Morton Gentler and Grant R. Hagen, June 1967.

6. Blagoveshchensky, N., Theory of Ship's Motions, Dover Publications, Inc., New York, New York, 1962.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor George J. Thaler, Code 52 Tr Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	5
4.	Assoc. Professor Alex Gerba, Jr., Code 52 Gz Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
5.	Assoc. Professor Milton L. Wilcox, Code 52 Wx Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
6.	CDR A. Skolnik, USN Surface Effect Ships Project Office P.O. Box 34401 Washington, D. C. 20034	1
7.	Mr. Sid Davis, Code PM-17 Department of the Navy Surface Effect Ships Project Office P.O. Box 34401 Washington, D. C. 20034	1
8.	Mr. James E. Blalock Department of the Navy Naval Ship Research and Development Center Carderock, Laboratory Bethesda, Maryland 20034	1
9.	Mr. Arnold W. Anderson, Code 1731A.1 Department of the Navy Surface Effect Ships Project Office, PM-17 Bethesda, Maryland 20034	2

10. LCDR Lonnie F. Cagle, USN — 1
P.O. Box 96
Dixon, California 95620

11. LT. Kenneth R. Myers, USN — 1
226 Solway Court
Timonium, Maryland 21093

12. Assoc. Professor Donald M. Layton, Code 57 Ln — 1
Naval Postgraduate School
Monterey, California 93940

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

ORIGINATING ACTIVITY (Corporate author)

Naval Postgraduate School
Monterey, California 93940

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

REPORT TITLE

Turning Characteristics of the Bell 100 Ton Surface Effect Ship

DESCRIPTIVE NOTES (Type of report and, inclusive dates)
Master's Thesis; June 1973

AUTHOR(S) (First name, middle initial, last name)

Kenneth Randall Myers

REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1973	145	6

CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
PROJECT NO.	
	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

ABSTRACT

The turning characteristics of the Bell 100 ton captured Air Bubble Surface Effect Ship (CAB/SES) are studied with the aid of the Oceanic Incorporated computer simulation. The craft's motions for straight runs, straight runs with waves and turning runs under calm water conditions, are compared with the final set of computer simulation turning maneuvers with waves involving changing speeds, wavelengths, wave amplitudes, and final rudder angles.

DD FORM 1 NOV 1473 (PAGE 1)
S/N 0101-807-6811

Security Classification

A-31408

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Surface Effect Ship						
SES						
Captured Air Bubble						
CAB						
Contained Air Bubble						
Rigid Sidewall Air Cushion Vehicle						

Thesis
M993 Myers
c.1 Turning characteristics of the Bell 100 ton surface effect ship.
145278

Thesis
M993 Myers
c.1 Turning characteristics of the Bell 100 ton surface effect ship.
145278

thesM993
Turning characteristics of the Bell 100
3 2768 000 99383 6
DUDLEY KNOX LIBRARY